Rapid Refresh / Rapid Update Cycle (RR/RUC) Technical Review

NOAA/ESRL/GSD/AMB

Stan Benjamin, Bill Moninger
Steve Weygandt, John M. Brown
Curtis Alexander, Kevin Brundage
Dezso Devenyi, Mike Fiorino
Georg Grell, Ming Hu
Brian Jamison, Bernie Johnson
Joe Olson, Steven Peckham
Susan Sahm, Tom Schlatter
Tanya Smirnova, Shan Sun
Tracy Lorraine Smith, Doug Koch
Barry Schwartz

NCEP/EMC – Geoff Manikin

Tues 3 Nov 2009

Major transitions:

- RUC13 changes – Nov 08, Mar 09
  - radar reflectivity assimilation, TAMDAR, mesonet, cloud analysis
- Rapid Refresh – final testing, planned for NCEP implementation – 4Q-FY10
- HRRR – now CONUS-wide

RUC/RR occupy central role in NOAA guidance for aviation, severe weather, AQ, energy, other applications

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

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Other key partners in RR/HRRR include:

GSD:	Bob Lipschutz	Chris Harrop
	Craig Tierney	Leslie Hart
NCEP:	Geoff DiMego	Dennis Keyser
NCAR:	WRF, microphysics, Digital Filter	
DTC:	For GSI repository	

Tues 3 Nov 2009

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Rapid Refresh / RUC Technical Review - OUTLINE

1:30 – 1:45	RUC➔Rapid Refresh transition overview, NCEP RUC changes – 2008-09	Stan Benjamin
1:45 – 2:00	Observation impact experiments - TAMDAR aircraft obs w/ moisture, larger OSE	Bill Moninger
2:00 – 2:20	Rapid Refresh overview, assimilation –	Steve Weygandt, Ming Hu
2:20 – 2:30	-- Break --	
2:30 – 3:05	RR-WRF model development / testing – physics, cloud, chemistry, PBL	John Brown, Tanya Smirnova, Joe Olson
3:05 – 3:20	The HRRR and HCPF (HRRR prob forecast)	Curtis Alexander
3:20 – 3:30	Future of RR/HRRR/ens	Stan Benjamin

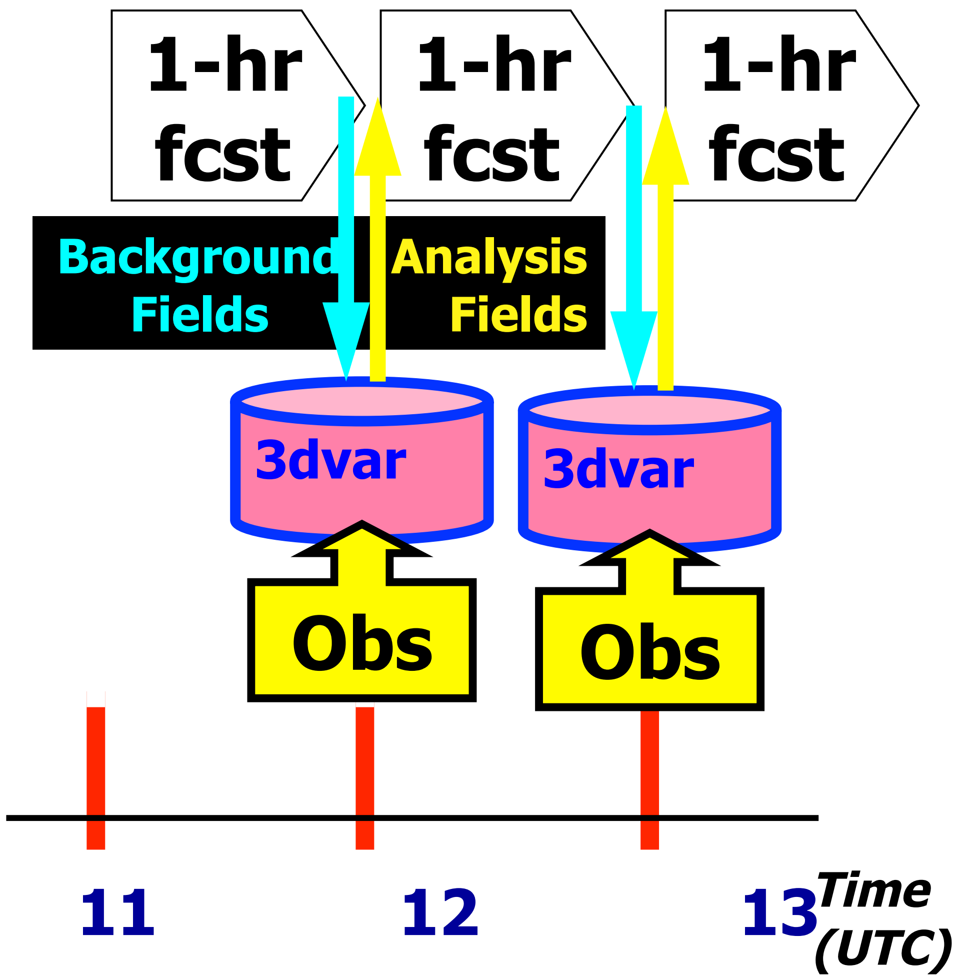
Why have a Rapid UC or Rapid Refresh?

- Provide high-frequency (hourly) mesoscale analyses, short-range model forecasts
- Assimilate (“merge”) all available observations into single, physically consistent 3-d grid such that forecasts are improved
- Initial focus on aviation enroute & surface weather:
  - Thunderstorms, severe weather, winter storms
  - Icing, ceiling and visibility, turbulence
  - Detailed surface temperature, dewpoint, winds
  - Upper-level winds
- Users:
  - aviation/transportation
  - severe weather forecasting
  - hydrology, energy (load, renewable)

“Situational Awareness Model”

RUC/Rapid Refresh Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables



Hourly obs

Data Type	~Number
Rawinsonde (12h)	150
NOAA profilers	35
VAD winds	120-140
PBL – prof/RASS	~25
Aircraft (V,temp)	3500-10000
TAMDAR (V,T,RH)	200-3000
Surface/METAR	2000-2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~300
Mesonet (temp, dpt)	~8000
Mesonet (wind)	~4000
METAR-cloud-vis-wx	~1800
AMSU-A/B/GOES radiances – *RR only*	
Radar reflectivity/ lightning	1km

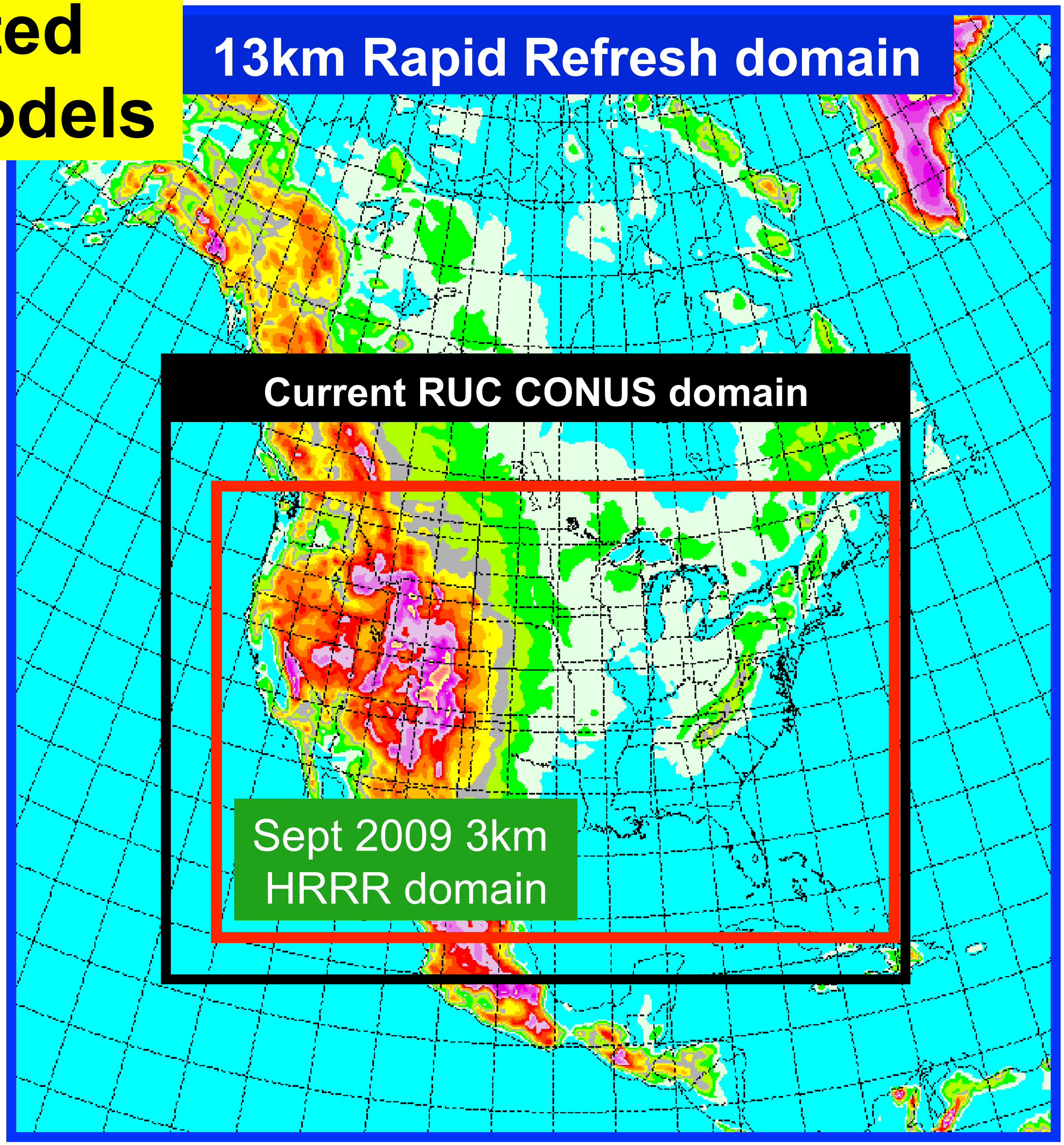
Hourly Updated NOAA NWP Models

RUC – current oper model - 13km

Rapid Refresh (RR) – replace RUC at NCEP in 2010 - WRF, GSI w/ RUC-based enhancements

HRRR - Hi-Res Rapid Refresh -Experimental 3km

12-h fcst updated every hour



Transition to Rapid Refresh (RR)

Purpose:

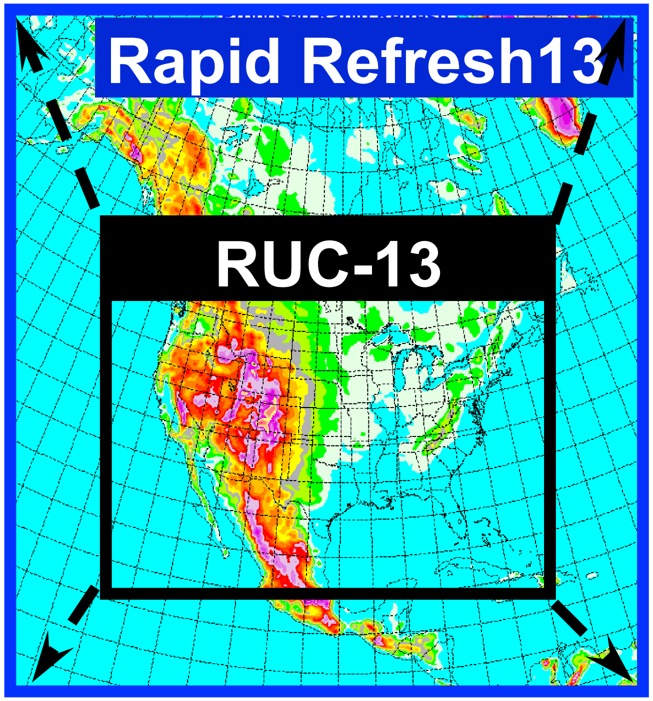
Evolutionary upgrade to NCEP operational RUC

- More advanced model and analysis components, community code for WRF, GSI)
- Retains aviation specific features from RUC (hourly cycle, cloud analysis, use of surface observations)
- Consistent grids over all of N.America for aviation hazards (convection, icing, turbulence, ceiling, visibility, etc.)

Status:

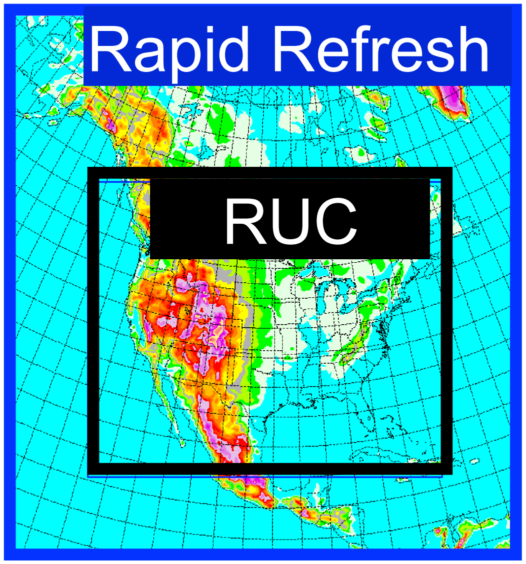
RR system approaching maturity.
NCEP implementation expected Q4 2010

- Refinements ongoing
- http://rapidrefresh.noaa.gov



RUC to Rapid Refresh

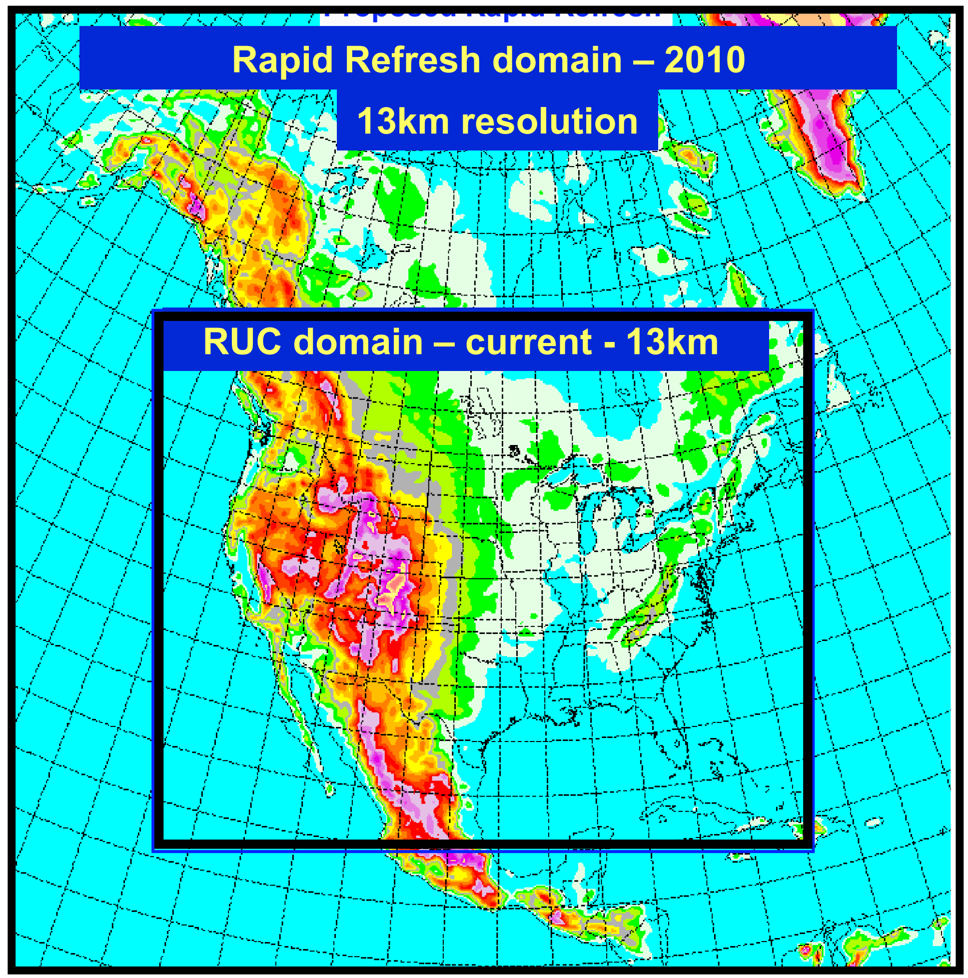
- CONUS domain (13km) → North American domain (13km)
- RUC 3DVAR → GSI (Gridpoint Statistical Interpolation) (incl. RR enhancements)
- RUC model → WRF-ARW Model (RR version)



RUC upgrades since fall 2007

http://ruc.noaa.gov
http://rapidrefresh.noaa.gov

- **11/17/08** - radar reflectivity assimilation, RRTM longwave radiation, 12/16/08 - TAMDAR assimilation
- **3/31/09** - improved cloud analysis, snow cover trimming using satellite data
- **12/09 - 01/10** - RUC extension to 18h forecasts every hour



Nov 2008 Changes for oper RUC upgrade

- **<u>Assimilation</u>**
  - **Use of radar reflectivity in RUC**
  - **Mesonet winds using mesonet station uselist**
  - **TAMDAR aircraft observations (16 Dec 2008)**
- **<u>Model physics</u>**
  - **RRTM longwave radiation - eliminates sfc warm bias**
  - **Mods to convective scheme, land-surface scheme**
- **<u>Post-processing</u> – add reflectivity fields, improved RTMA downscaling**

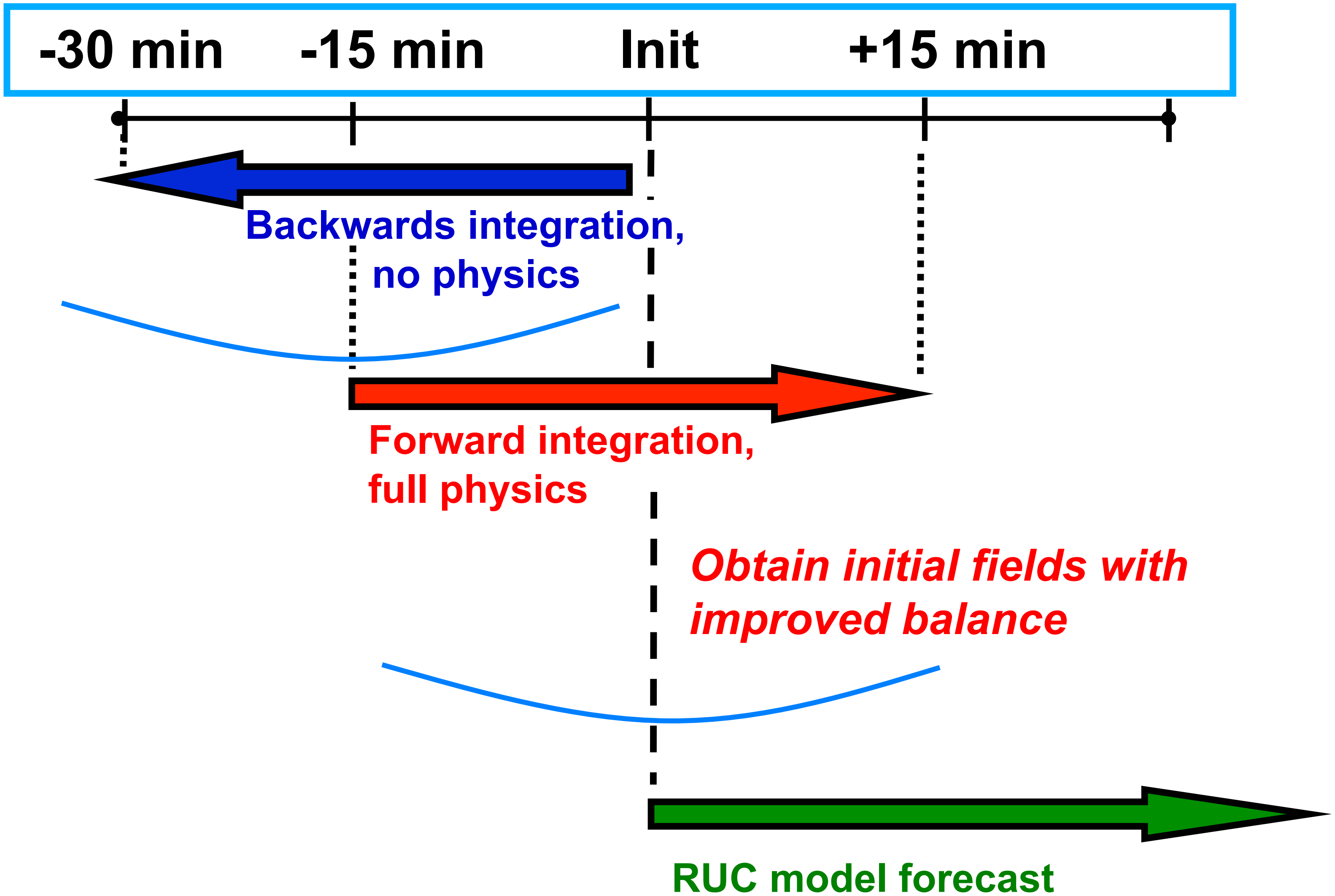
March 2009

- **Added snow cover trimming using daily NESDIS snow analysis**
- **Important improvement to cloud analysis for retention of METAR and GOES cloud obs**

RUC Diabatic Digital Filter Initialization (DDFI)

Initial DFI in RUC model at NCEP - 1998 - adiabatic DFI

Diabatic DFI introduced at NCEP - 2006



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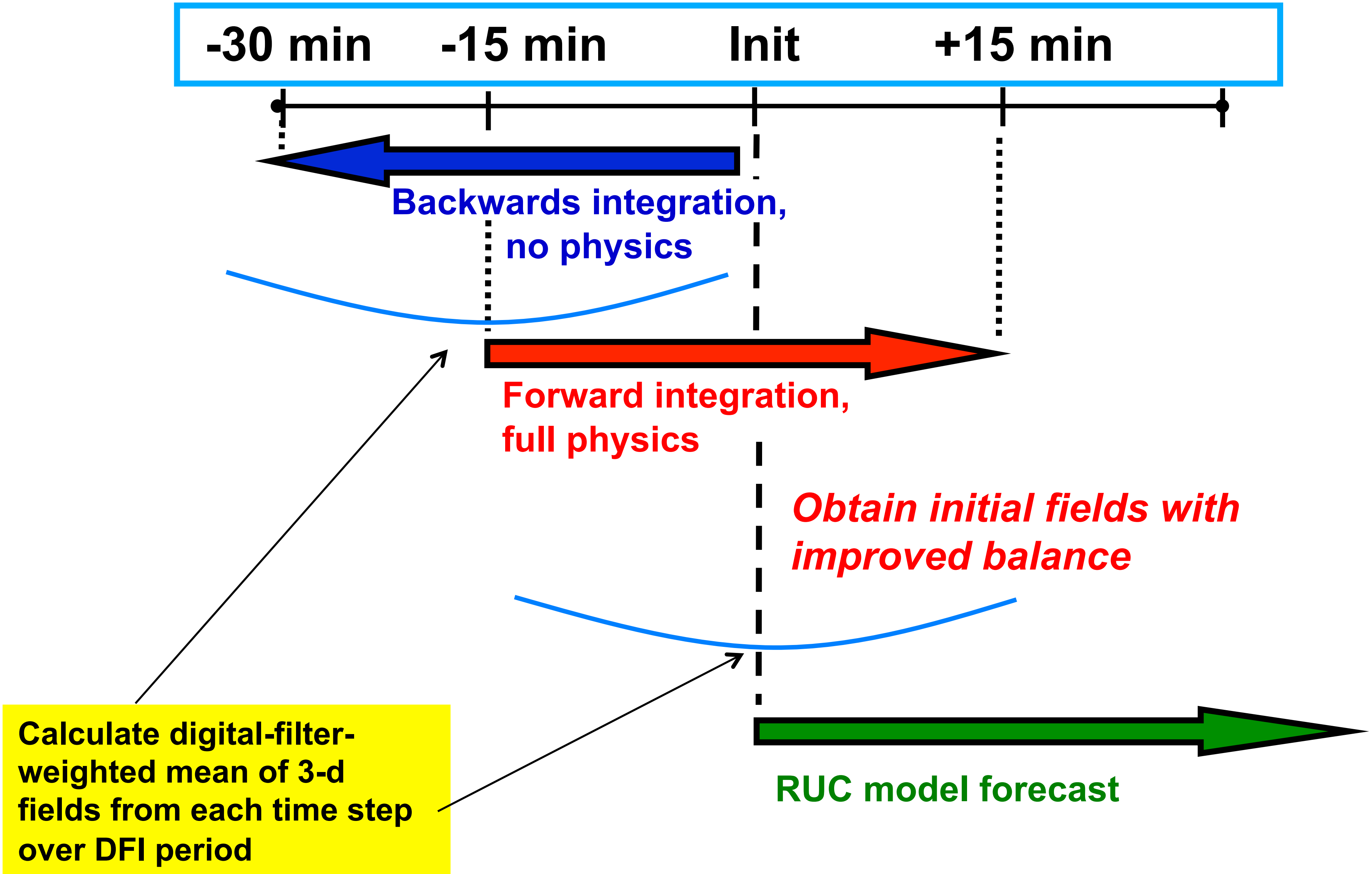
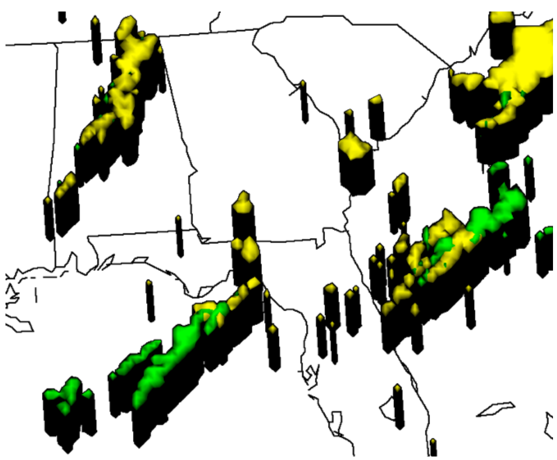


Diabatic Digital Filter Initialization (DDFI)

New - add assimilation of radar data

-30 min -15 min Init +15 min

Backwards integration,
no physics



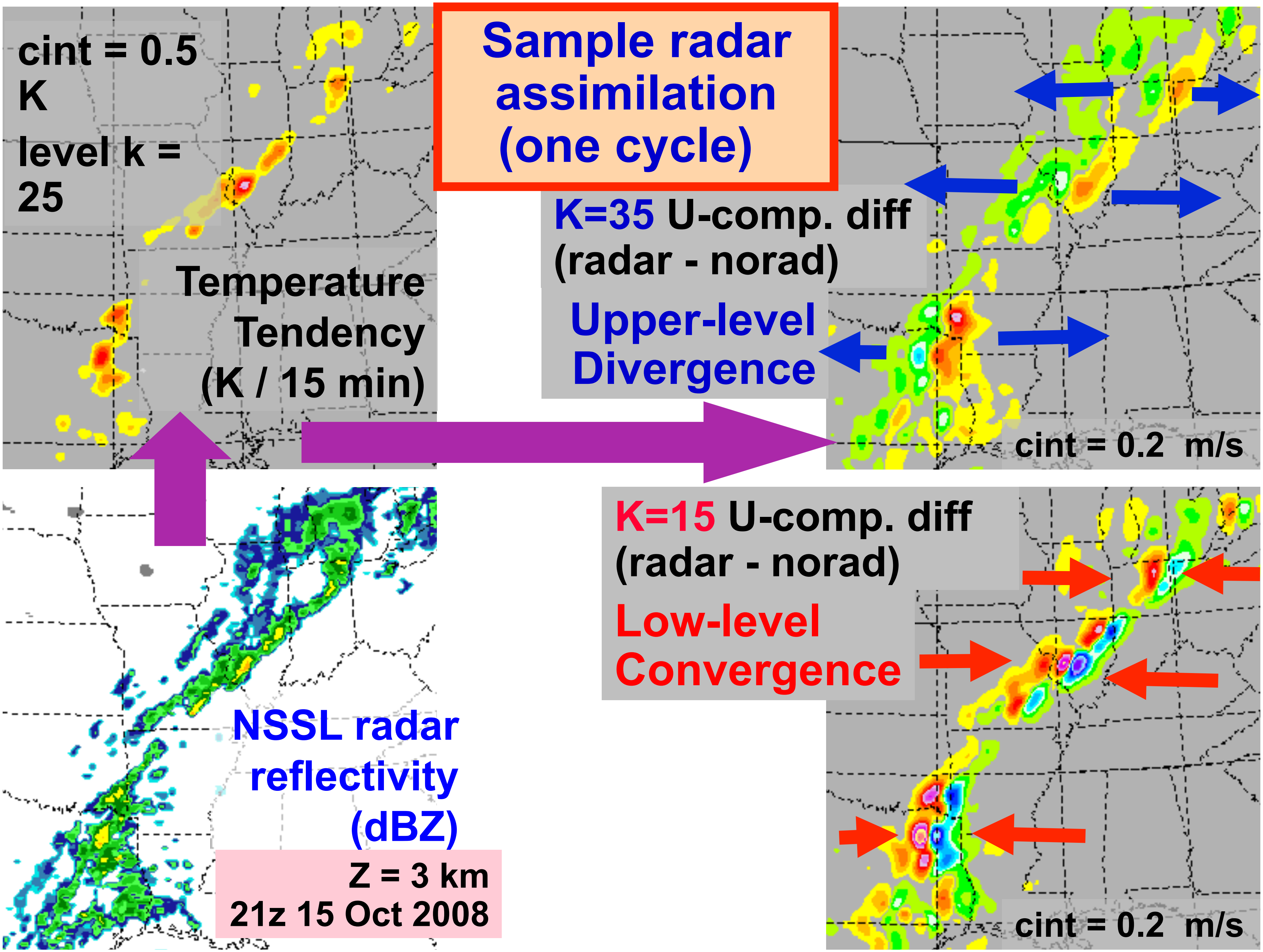
Forward integration,
full physics

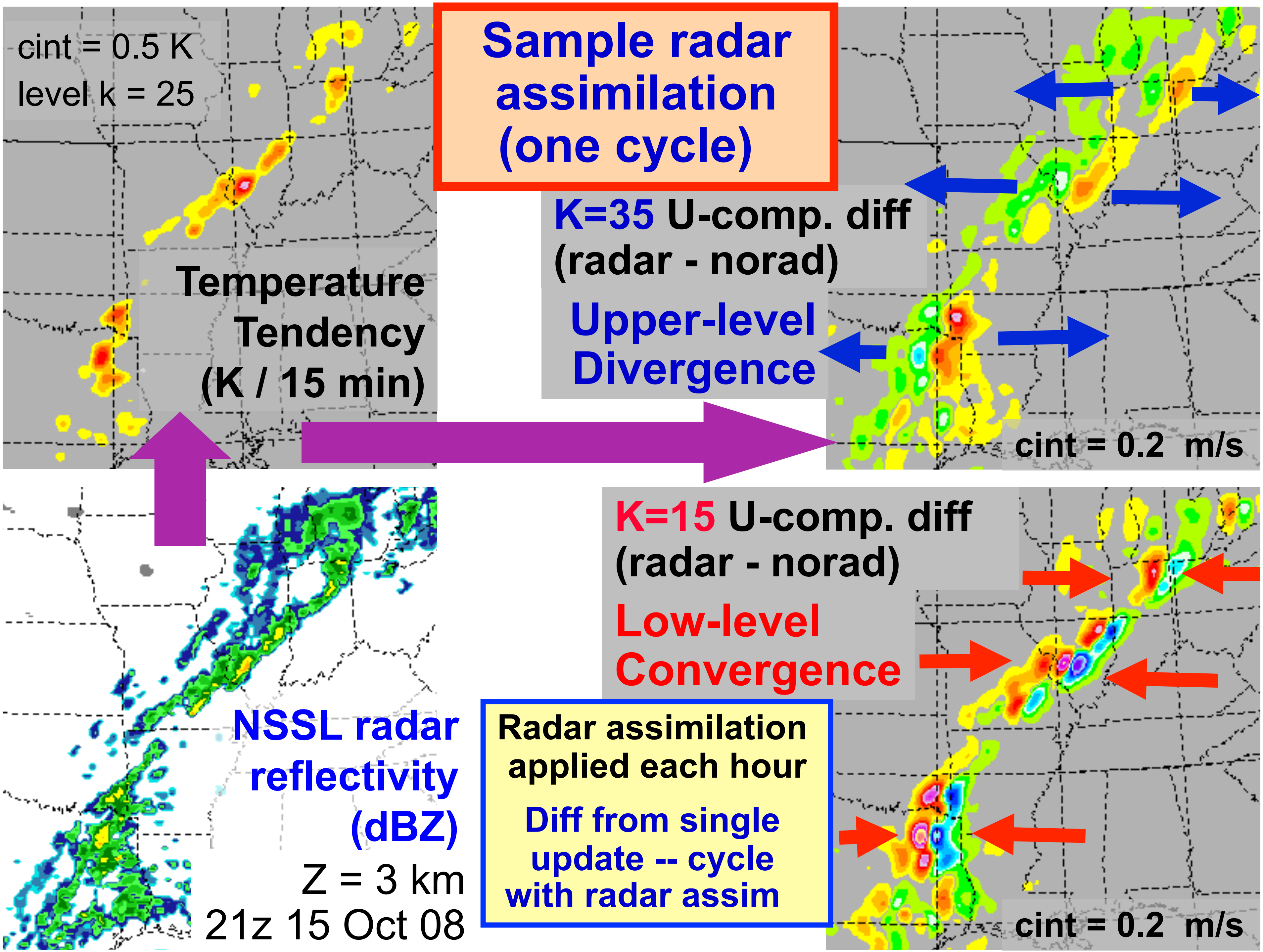
Specify 3-d
latent heating
from radar
reflectivity,
lightning
data (where
available)

Obtain initial fields with
improved balance,
vertical circulations
associated with
ongoing convection

RUC model forecast

Radar reflectivity assimilation in RUC


Sample radar assimilation (one cycle)
cint = 0.5 K
level k = 25
Temperature Tendency (K / 15 min)
K=35 U-comp. diff (radar - norad)
Upper-level Divergence
cint = 0.2 m/s
NSSL radar reflectivity (dBZ)
Z = 3 km
21z 15 Oct 2008
K=15 U-comp. diff (radar - norad)
Low-level Convergence
cint = 0.2 m/s



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Low-level Convergence
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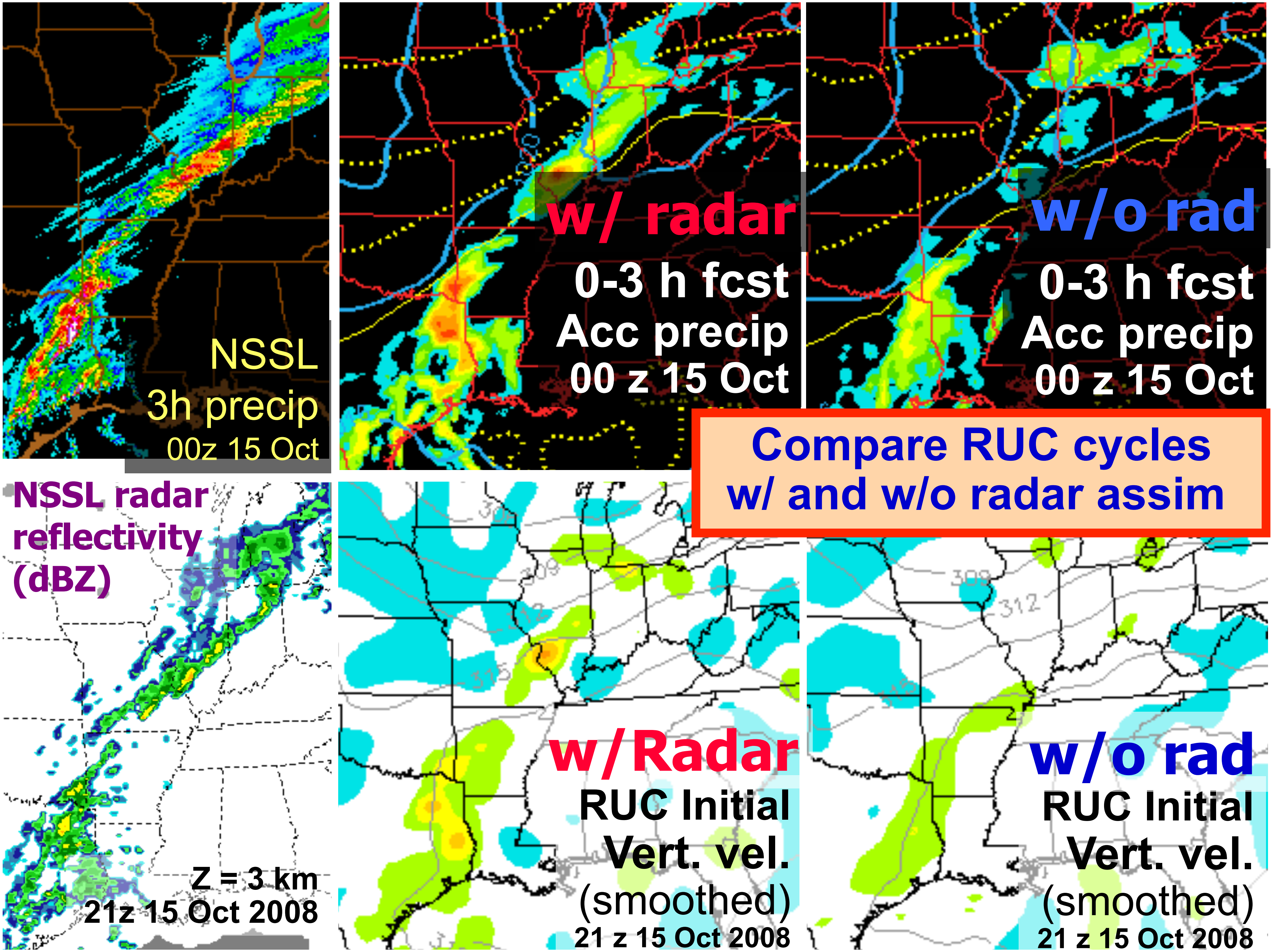
Z = 3 km
21z 15 Oct 08
Radar assimilation applied each hour
Diff from single update -- cycle with radar assim


NSSL
3h precip
00z 15 Oct
w/ radar
0-3 h fcst
Acc precip
00 z 15 Oct
w/o rad
0-3 h fcst
Acc precip
00 z 15 Oct
Compare RUC cycles
w/ and w/o radar assim
NSSL radar
reflectivity
(dBZ)
Z = 3 km
21z 15 Oct 2008
w/Radar
RUC Initial
Vert. vel.
(smoothed)
21 z 15 Oct 2008
w/o rad
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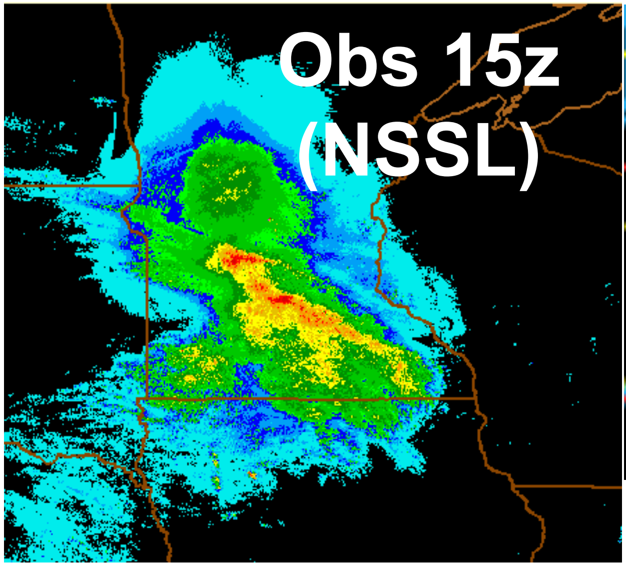
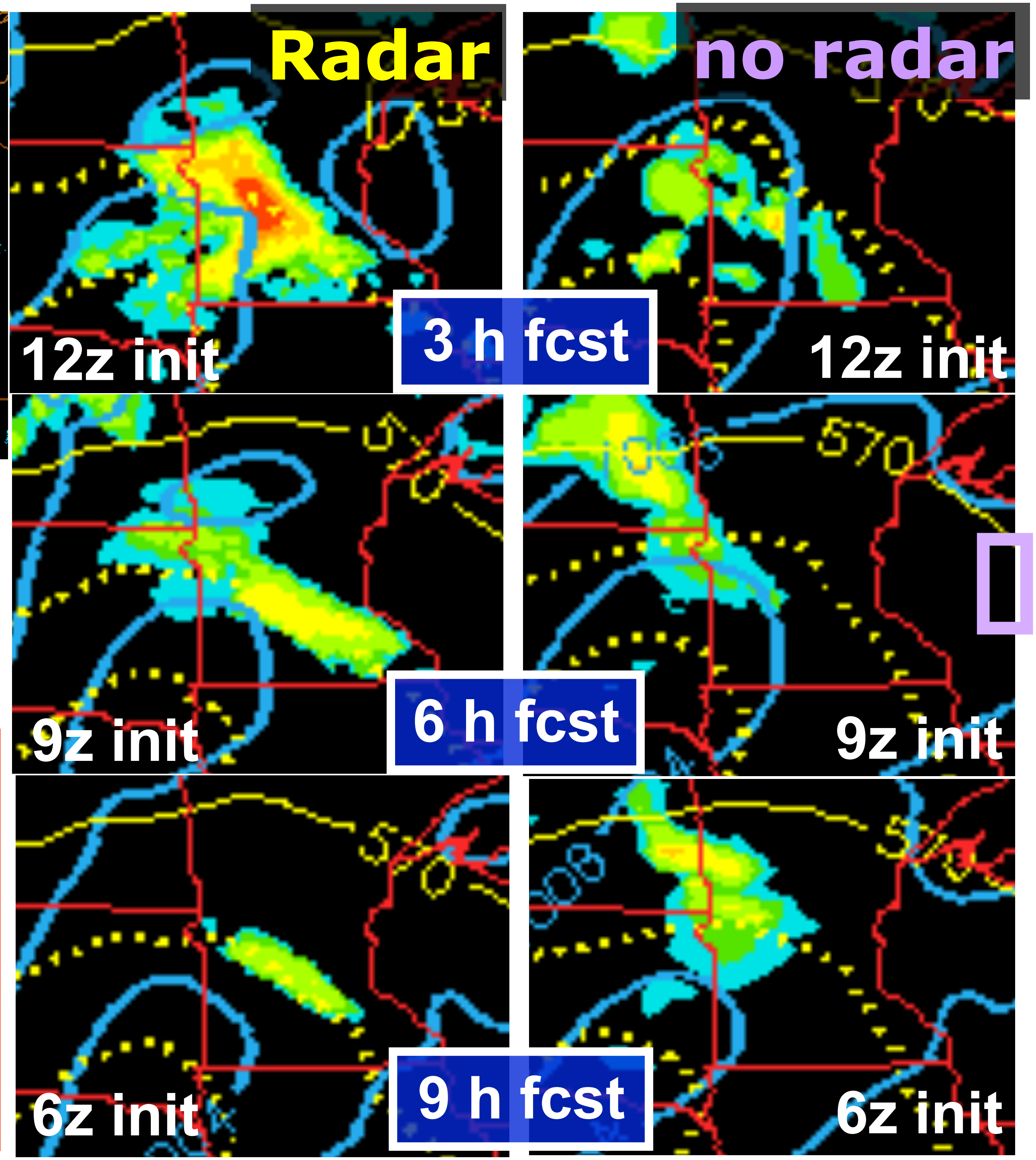




3-h acc. precip.

Valid 15z

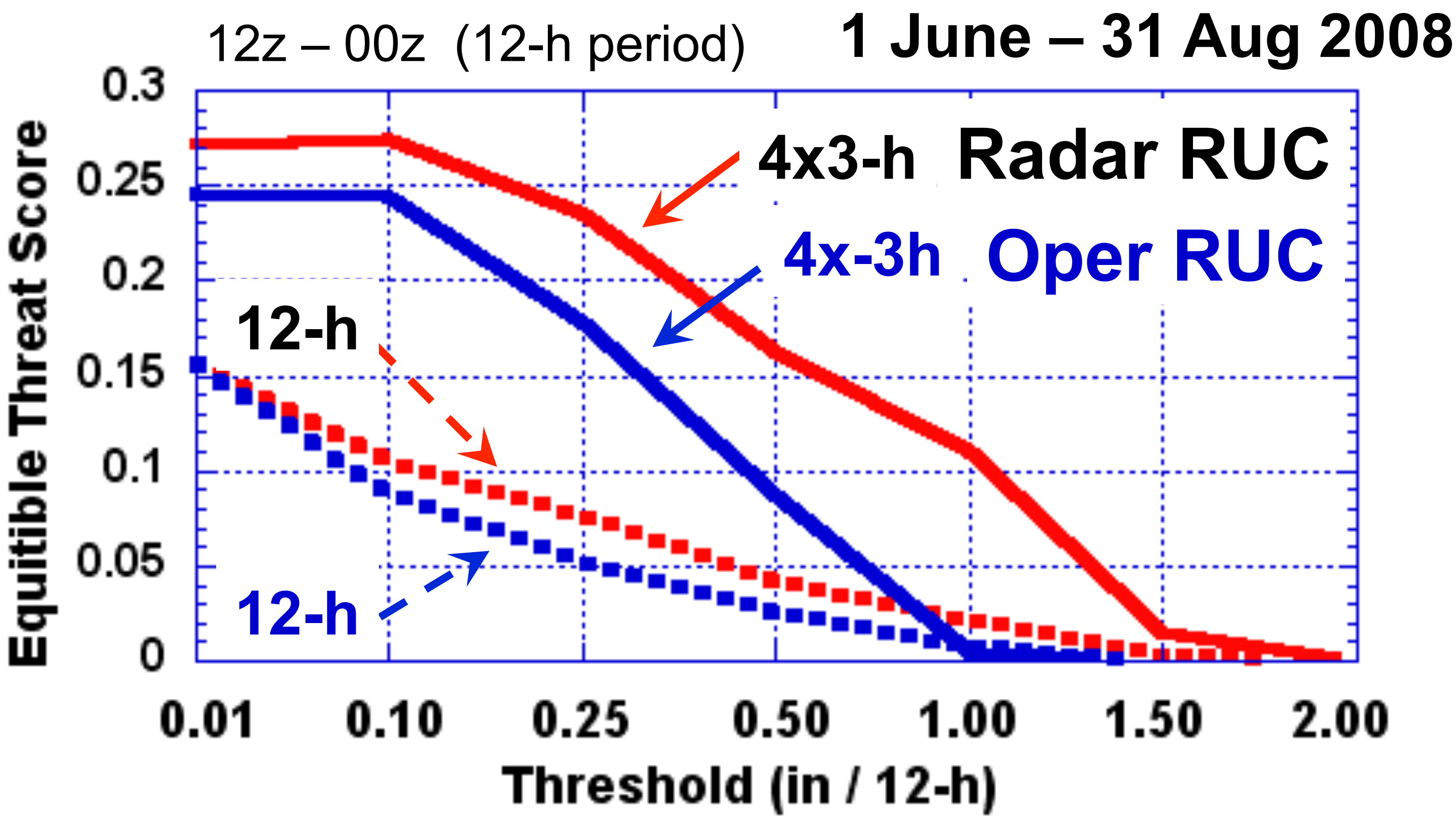
31 July 2008

RUC radar Assimilation

→Better RUC forecasts

Radar assimilation impact on RUC precipitation skill scores

- Four 0-3h forecasts vs. one 0-12h forecast
- Summer - Daytime



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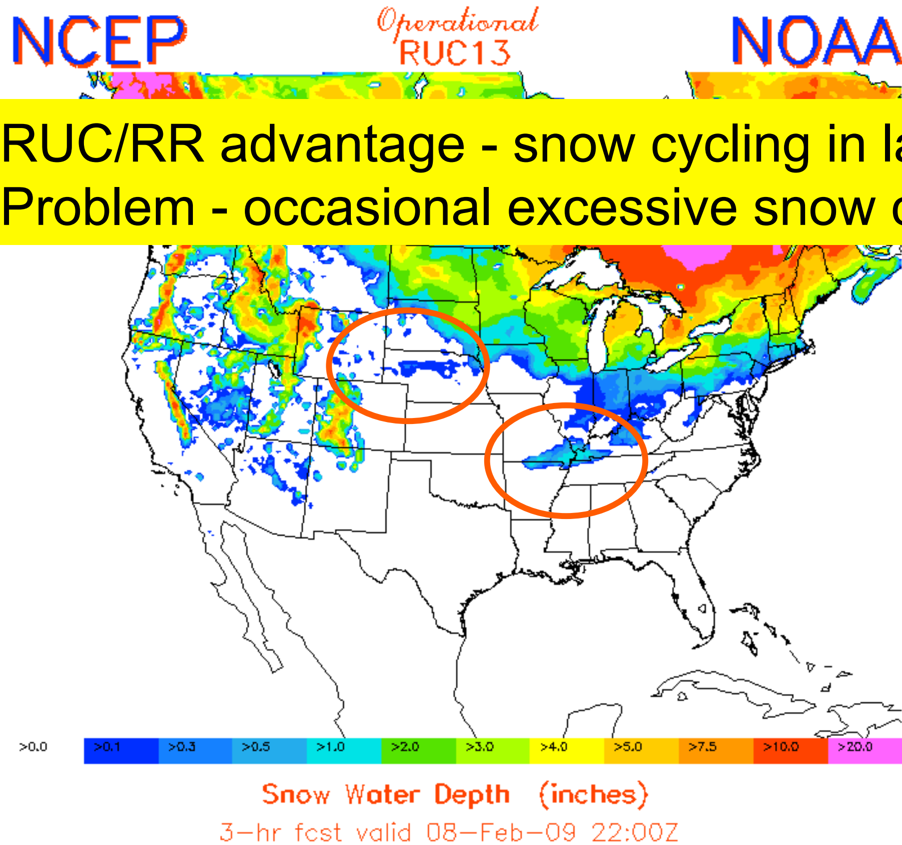
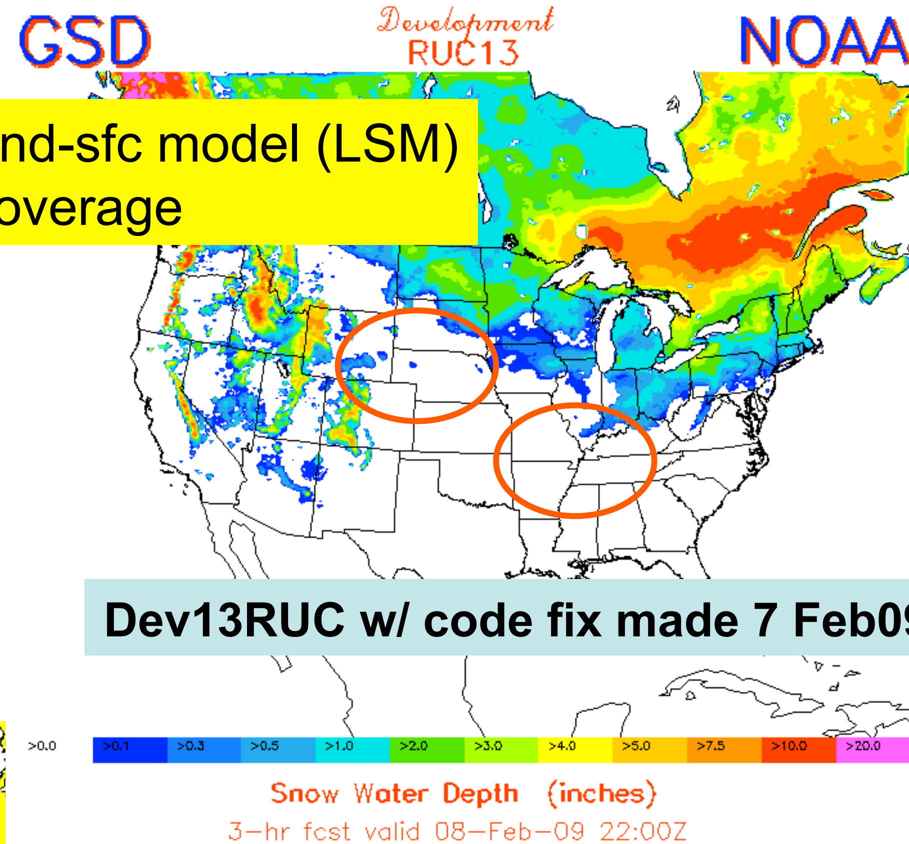
March 2009

- Added snow cover trimming using daily NESDIS snow analysis
- Important improvement to cloud analysis for retention of METAR and GOES cloud obs

RUC/RR advantage - snow cycling in land-sfc model (LSM)
Problem - occasional excessive snow coverage

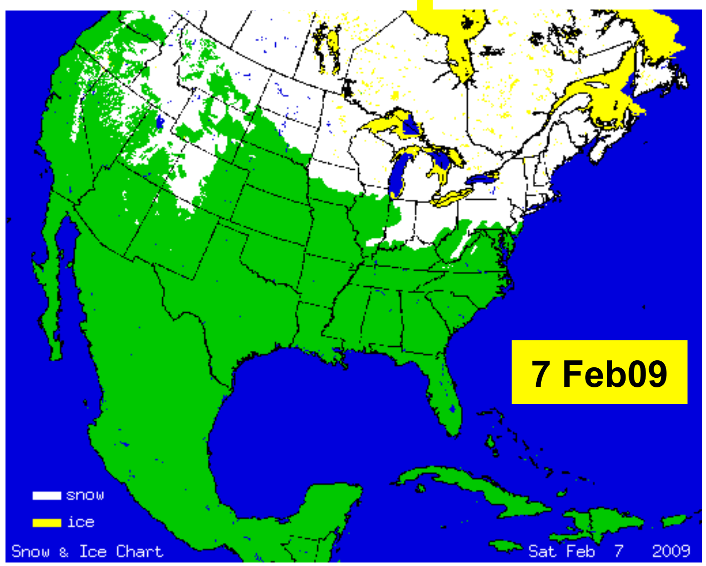




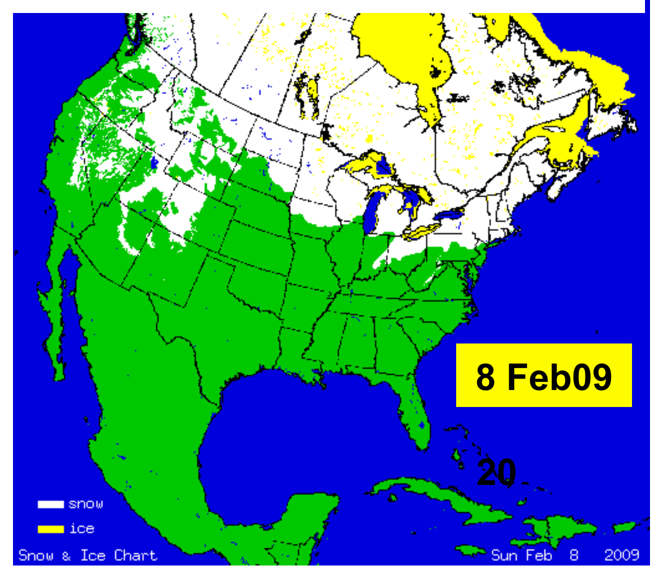
Dev13RUC w/ code fix made 7 Feb09

NESDIS snow cover

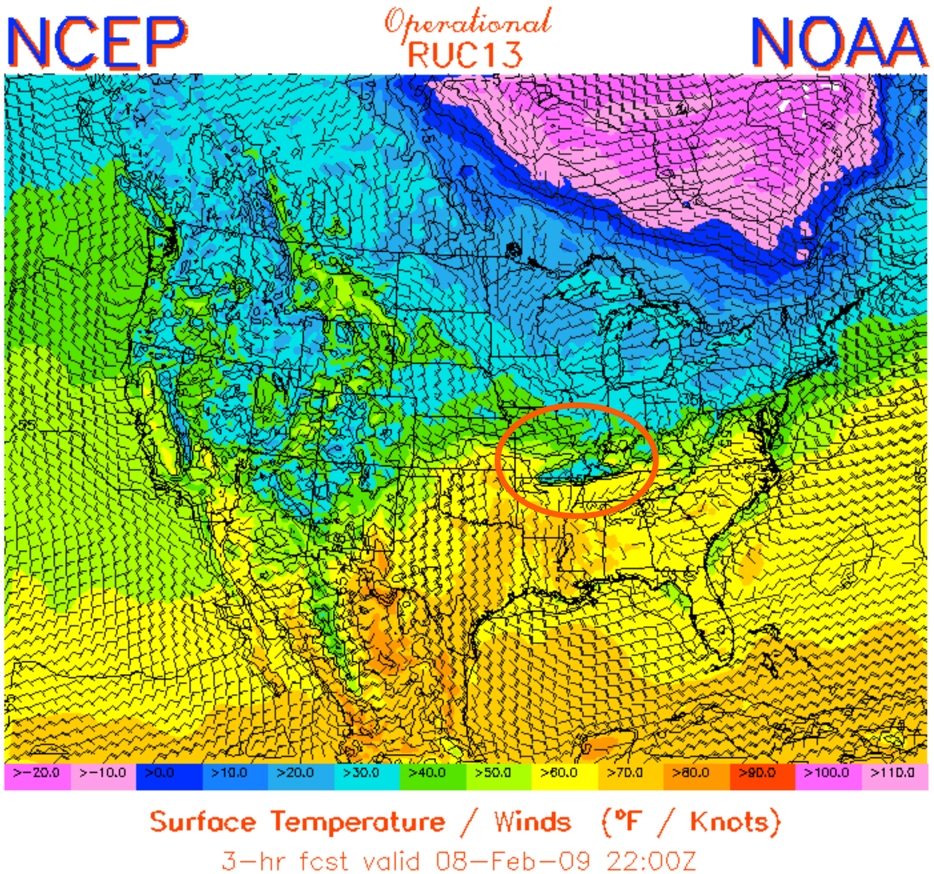
http://www.natice.noaa.gov/pub/ims_gif/DATA/cursnow_usa.gif

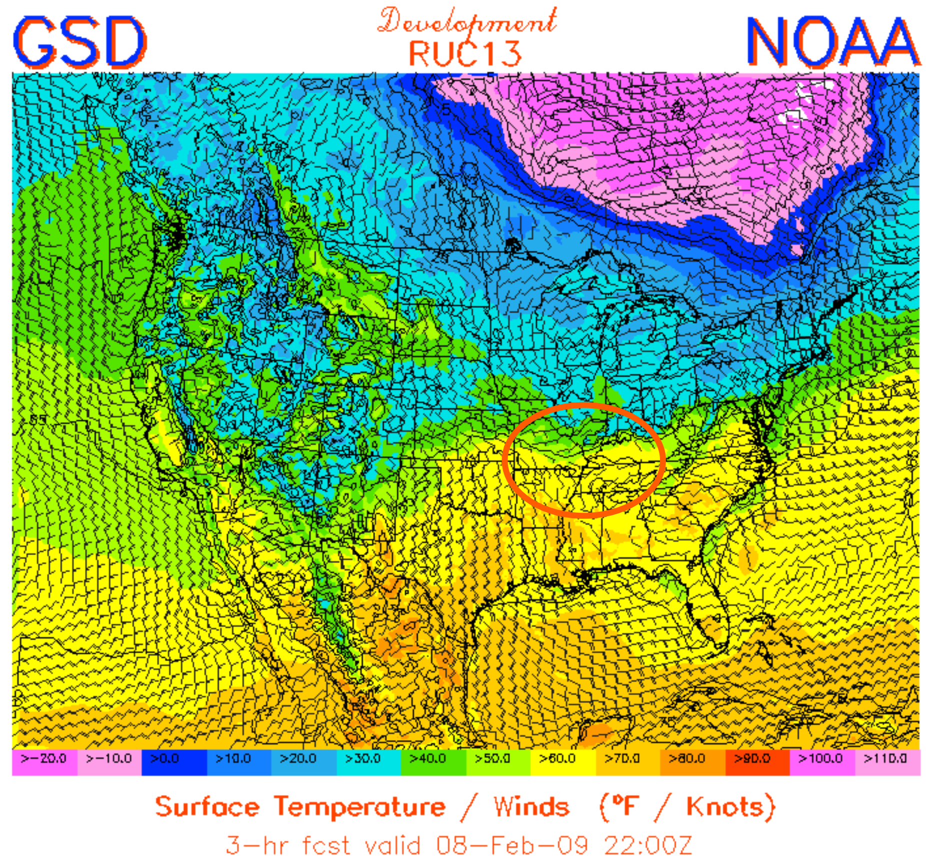


7 Feb09



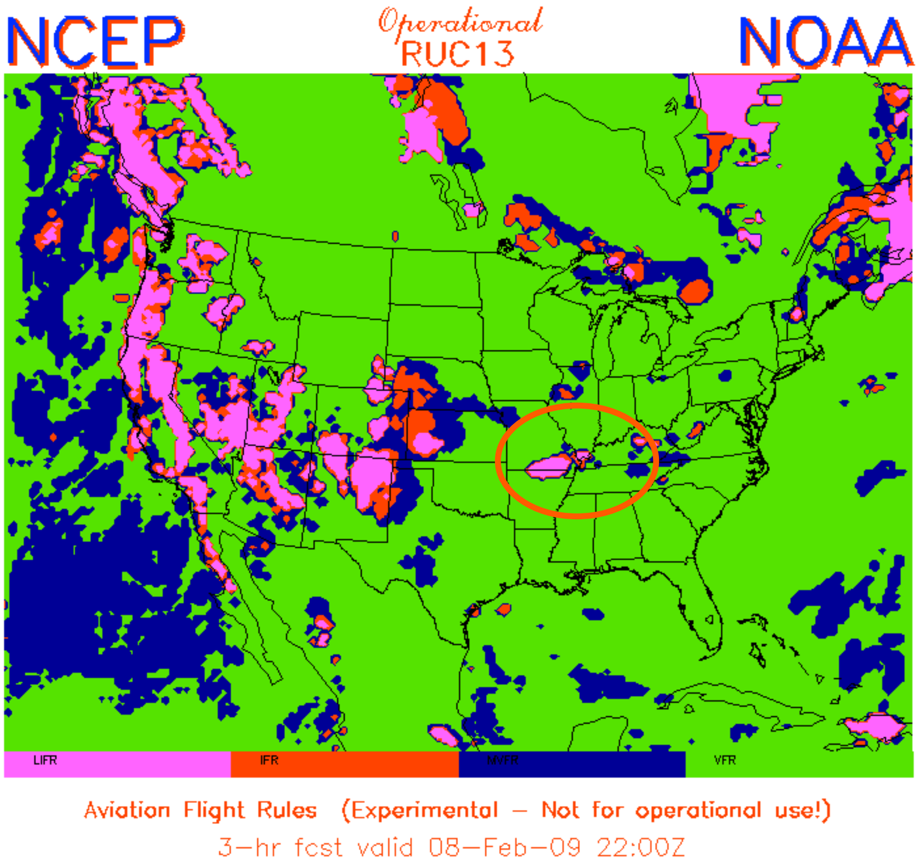
8 Feb09

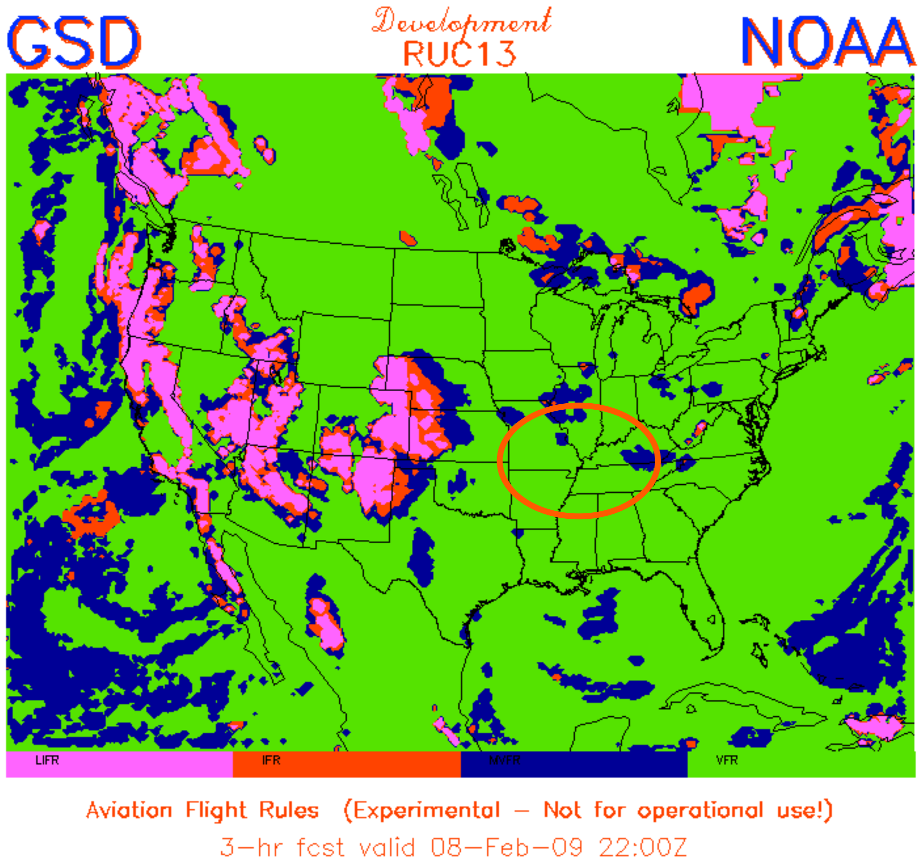




Errors in 2m temp due to erroneous snow cover in operational RUC

Improved 2m temp in dev13RUC with correction for NESDIS snow cover areal trimming.



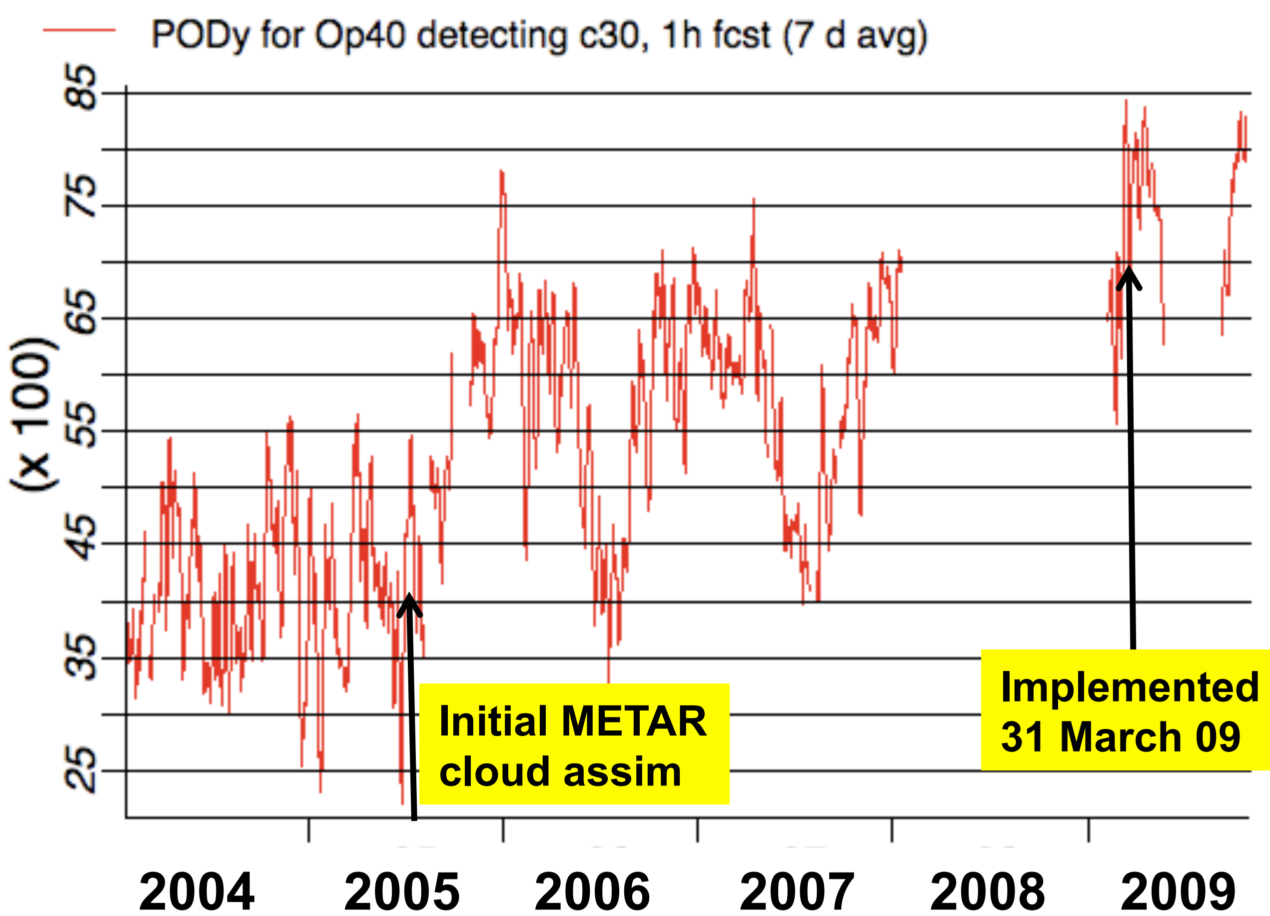


Another consequence from snow cover error:
Low fog due to erroneous snow cover in operational RUC

Improved cloud cover in dev13RUC with correction for NESDIS snow areal trimming.

Mar 09 mods to RUC hydrometeor analysis

– ensures saturation for cloudy volumes
– cloud analysis call moved to last step.



POD-yes for 3000-ft (MVFR) ceiling -1h RUC forecast (7-day average running mean)

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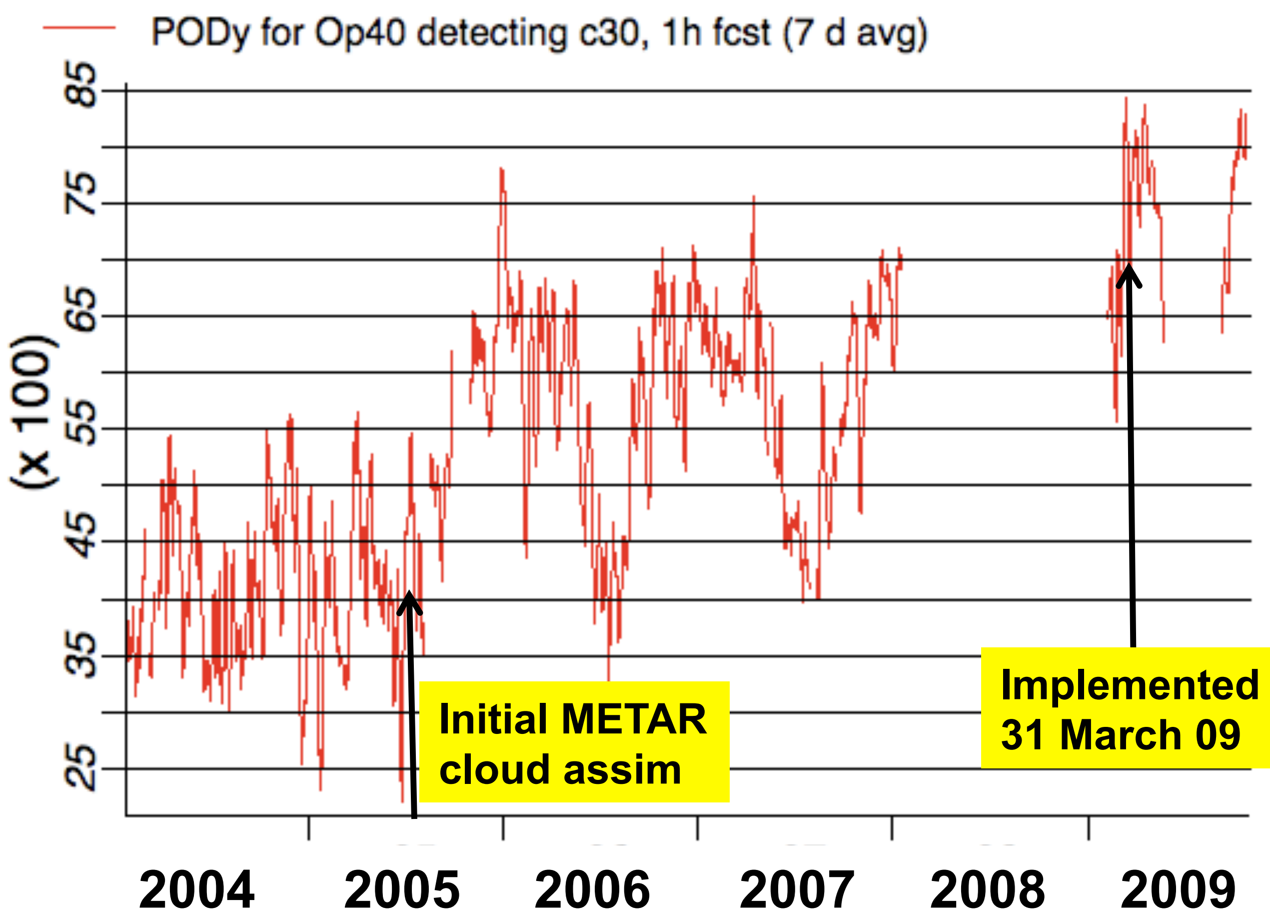


POD-yes for 3000-ft (MVFR) ceiling -1h RUC forecast (7-day average running mean)

(Common web-based verification (Moninger, Sahm) used for RUC, RR, FIM)

Nov 2009 – further changes for oper RUC – now in testing @ NCEP

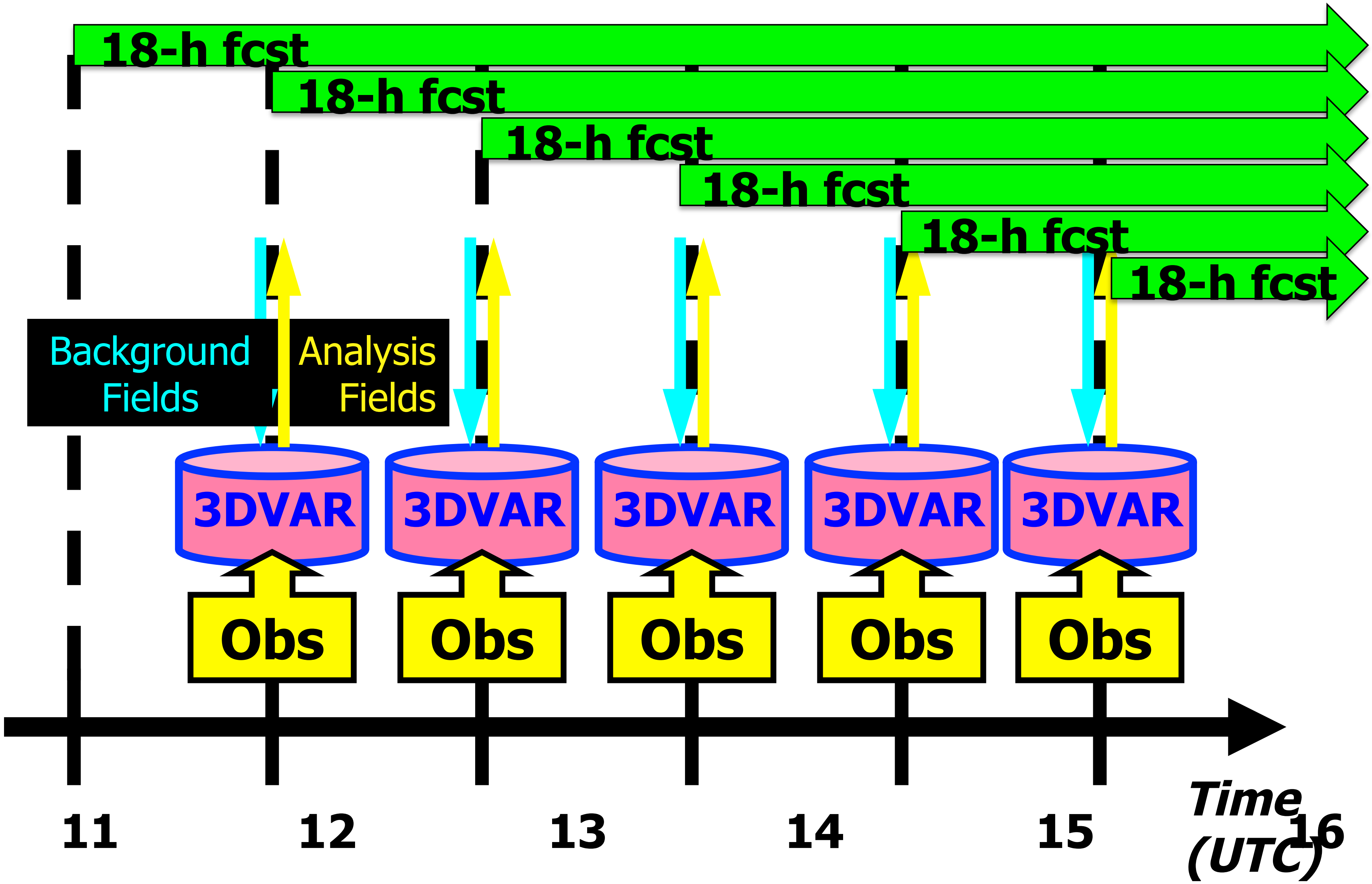
- **Extension of RUC to 18h every hour (requested by SPC and AWC)**

- **Further fix to cloud analysis**
  - **problem with saturation for warm clouds**

- **Addition of Canadian aircraft observations**
  - **1000-1200 reports / hour during flight ops hours**
  - **New study by GSD found that this data is now of good quality**
    - **Regional jets only, turboprops (bad headings) removed**

NOTE: All RUC changes have improved 2009 HRRR (via same changes in backup RUC @GSD) and transition to RR is complete or in process

18h RUC Hourly Assimilation Cycle - fall 2009



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Observation Sensitivity Experiments using the RUC and RR

- These allow us to assess the **impact** and **relative impact** of existing and proposed new operational data sources
- The RUC is an ideal basis for these tasks because
  - It is a state-of-the-art operational model
  - It ingests most currently available data, so new data are tested in a **realistic context**

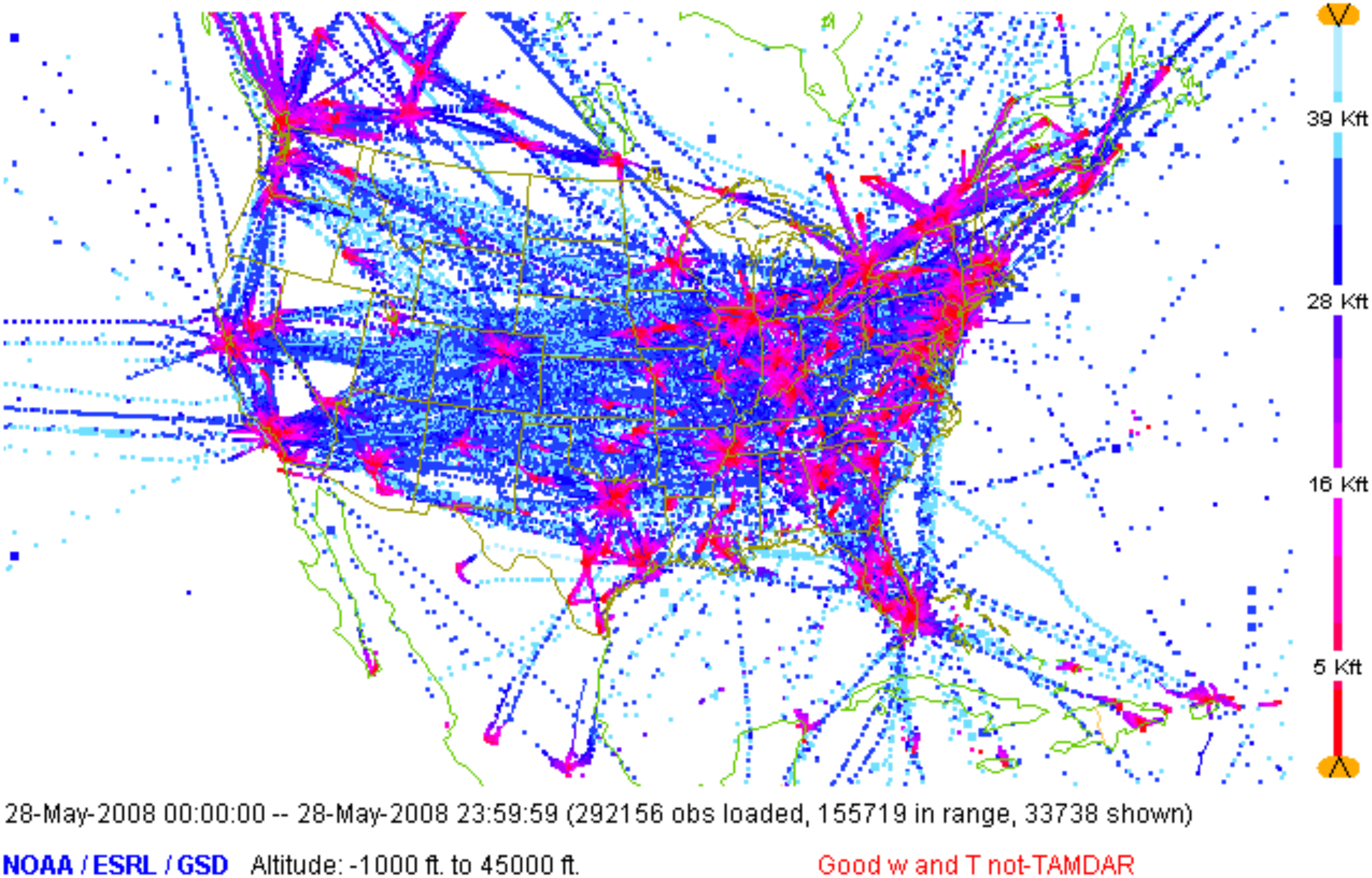
Why perform OSEs?

- The government is being asked to purchase or deploy new data systems.
  - Are they worth the money?
  - Will these systems improve relevant forecasts?
- Examples today:
  - TAMDAR
  - A wide variety of existing systems

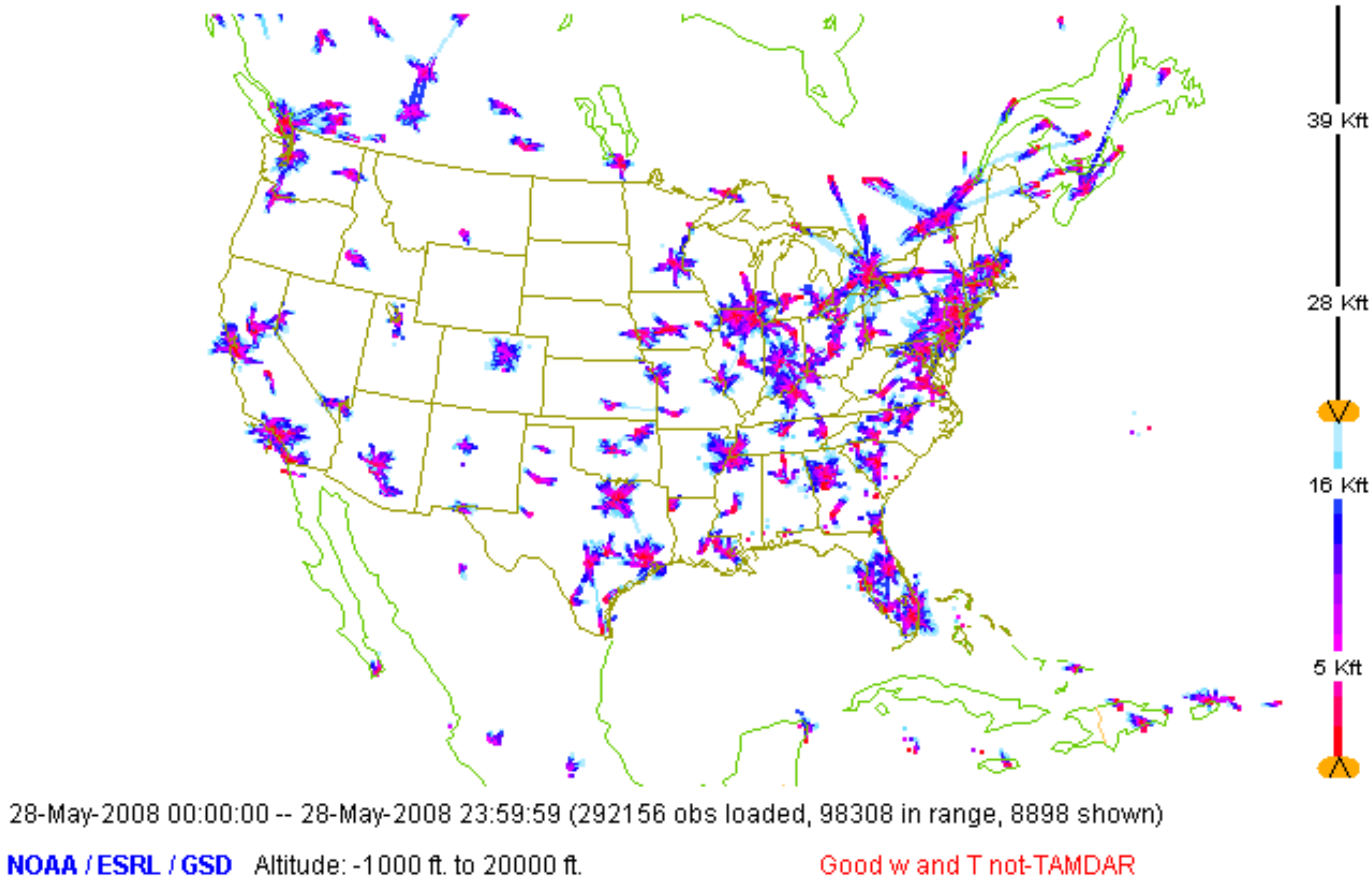
TAMDAR

- A system that measures:
  - Wind, Temperature, Relative Humidity
- Installed on scheduled regional commercial aircraft
- Designed to fill a data-void region between major airports
- Developed by AirDat, LLC, initially under NASA sponsorship

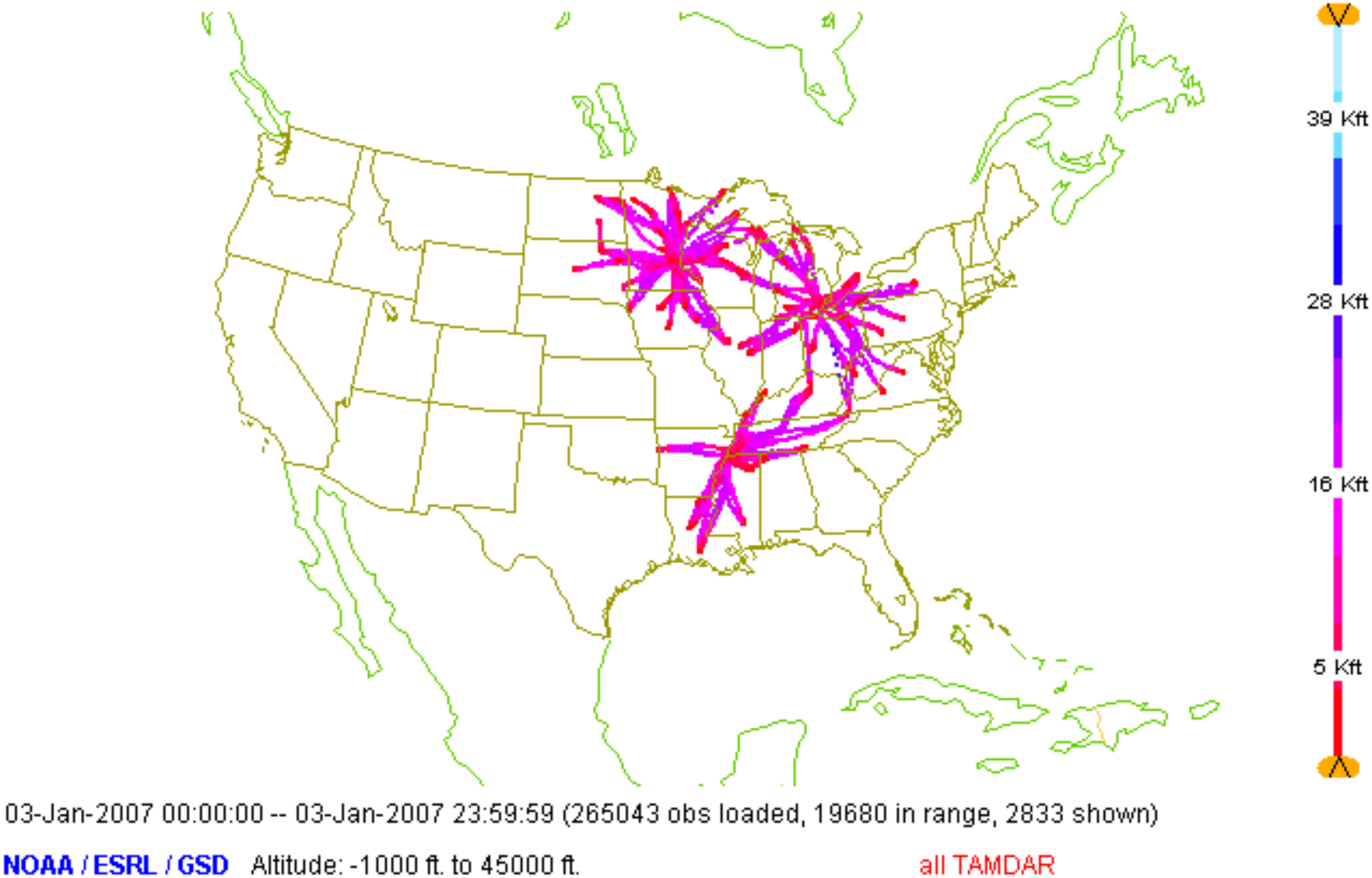
Over CONUS, all altitudes, traditional AMDAR jets
More than 125,000 observations in 24 h



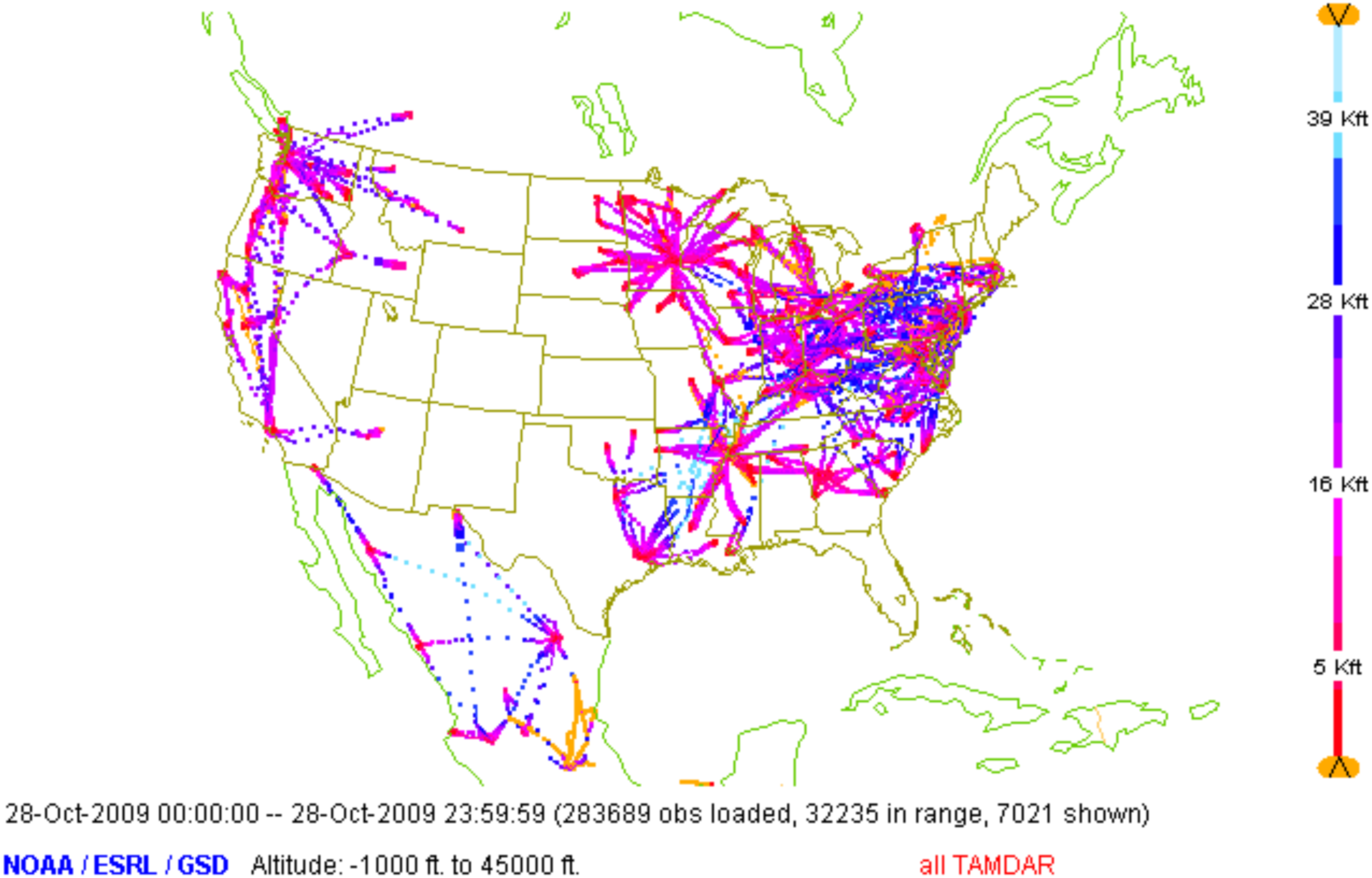
Coverage is limited to major hubs below 20 Kft, (without TAMDAR)



TAMDAR, Circa 2006-2007



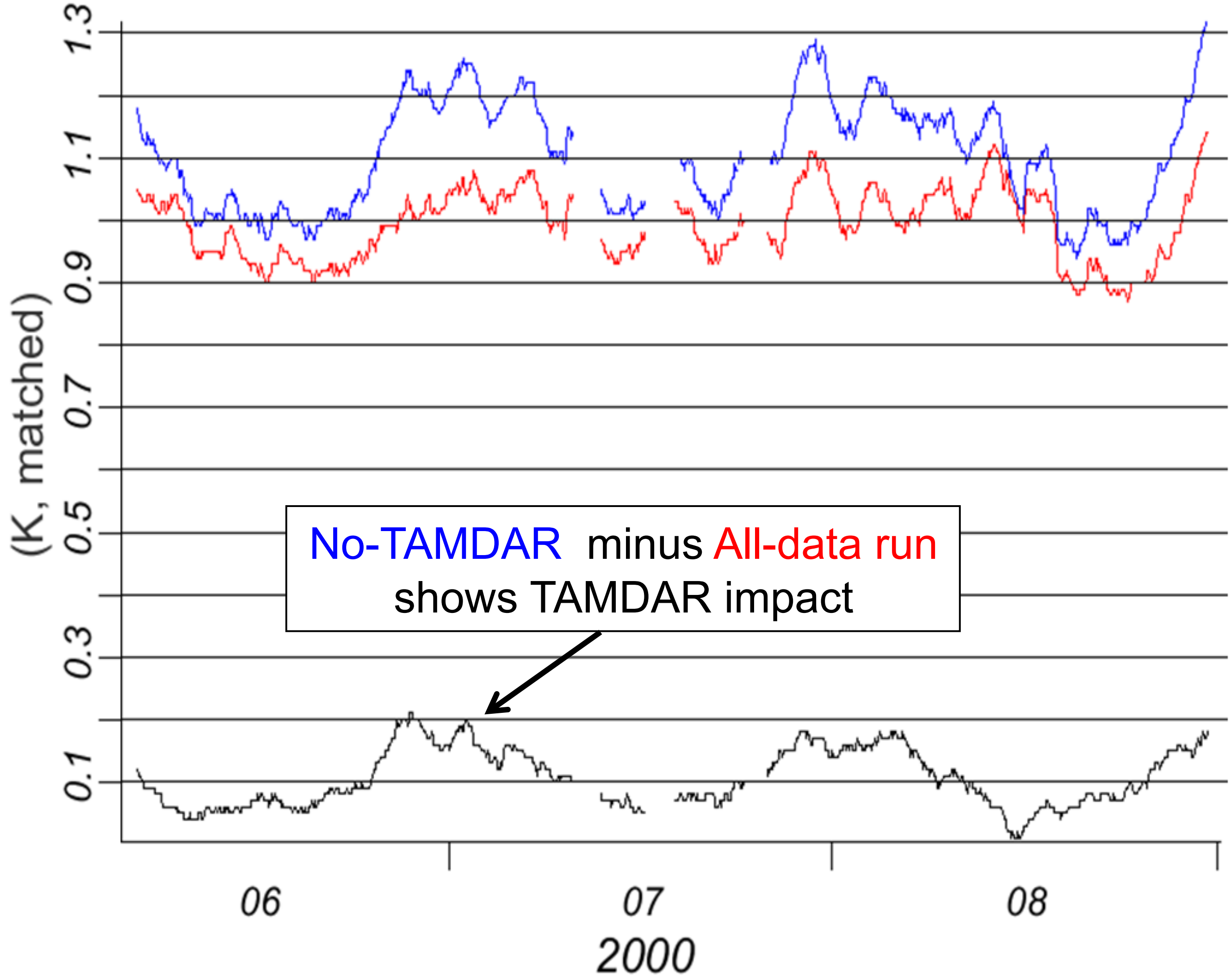
TAMDAR, current time (also in Alaska)



Parallel *real-time* RUC cycles

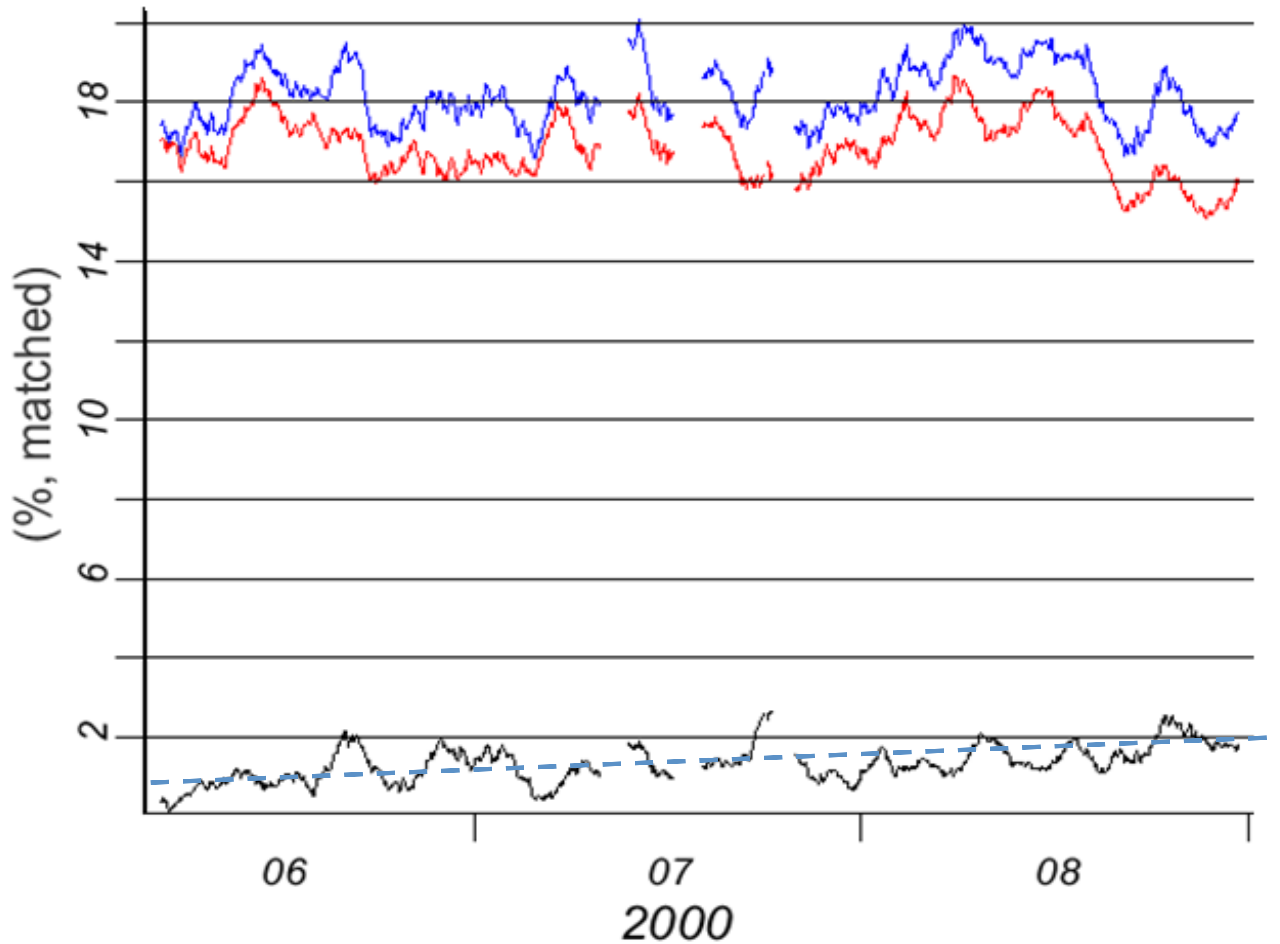
- One **with** TAMDAR data, one **without**
- Both run at 20-km, but are otherwise use same code as the (then) operational 13-km runs
- A **3-year long** parallel experiment at 20km
- (Continued to the present with 13-km TAMDAR and no-TAMDAR runs)

3-h Temperature forecast errors at 00 UTC, Great Lakes Region surface to 500 hPa. 30 dav averages



TAMDAR impact on **short-term T forecasts** is strong and consistent over time (greatest when model errors are largest)

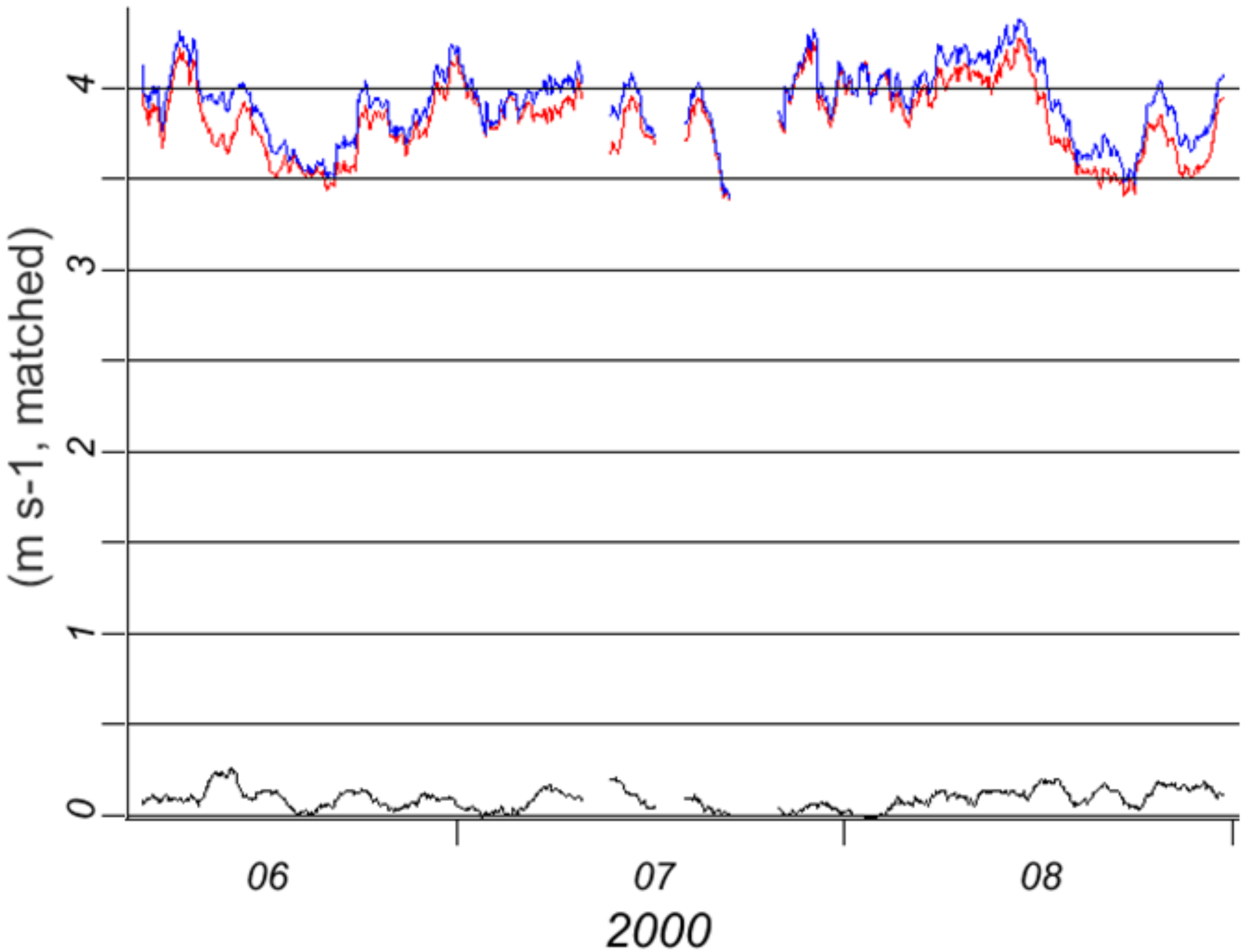
3-h Relative Humidity forecast errors at 00 UTC,
Great Lakes Region
surface to 500 hPa, 30 day averages



TAMDAR impact on **short-term RH fcsts** is strong and consistent over time

The effect of additional fleets is evident in the **gradual increase in RH impact**

3-h Wind forecast errors at 00 UTC, Great Lakes Region
surface to 500 hPa, 30 day averages



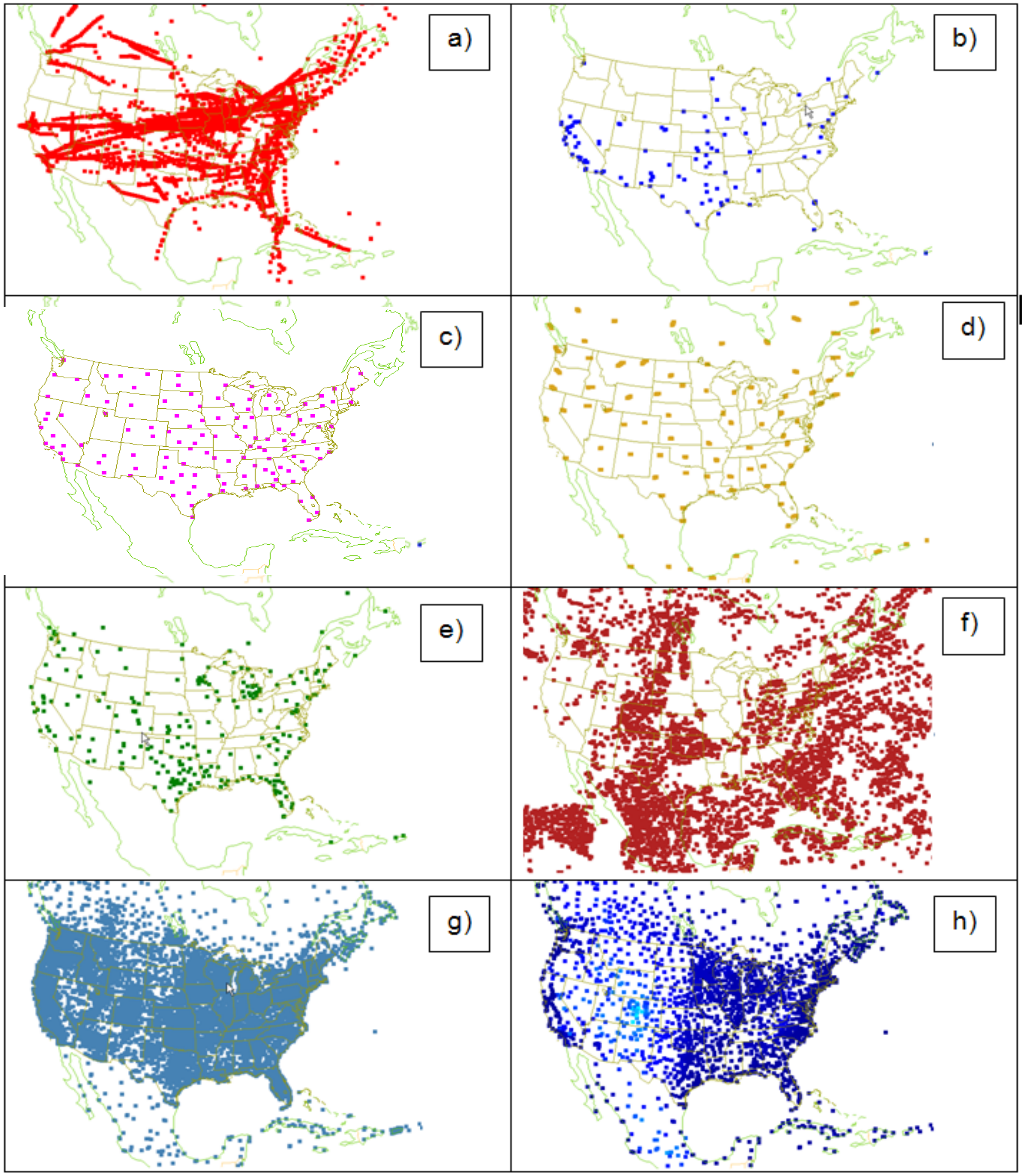
TAMDAR impact on **short-term wind fcsts** is limited, but positive

We discovered that turboprop fleets provide **poor heading information**.

But the newer TAMDAR-equipped regional jet fleets starting in 2008 improve wind impact.

Retrospective OSEs

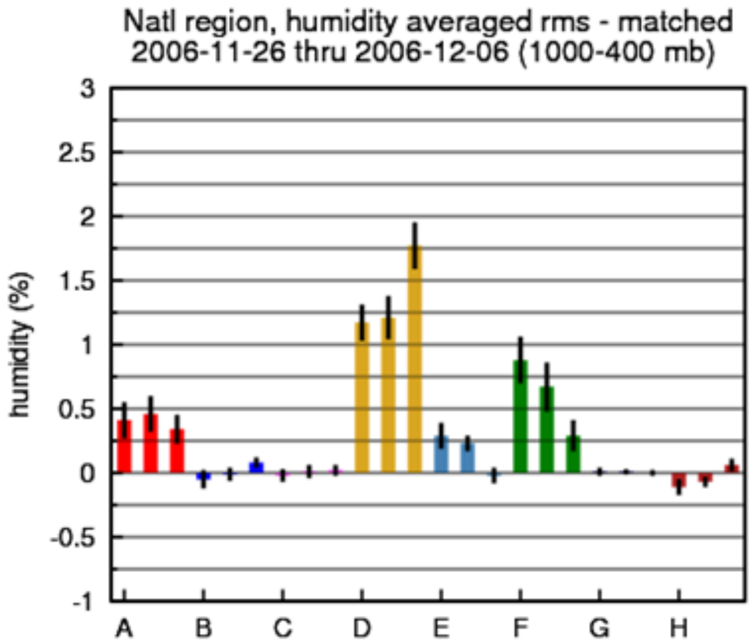
- For a wider range of data-suite comparisons, we use *retrospective periods* over which we can run multiple OSEs
- We focus on two 10-day periods
  - Fall 2006
  - August 2007
- We have run **51 cases** over these two periods
- Each takes about 5 days of supercomputer time

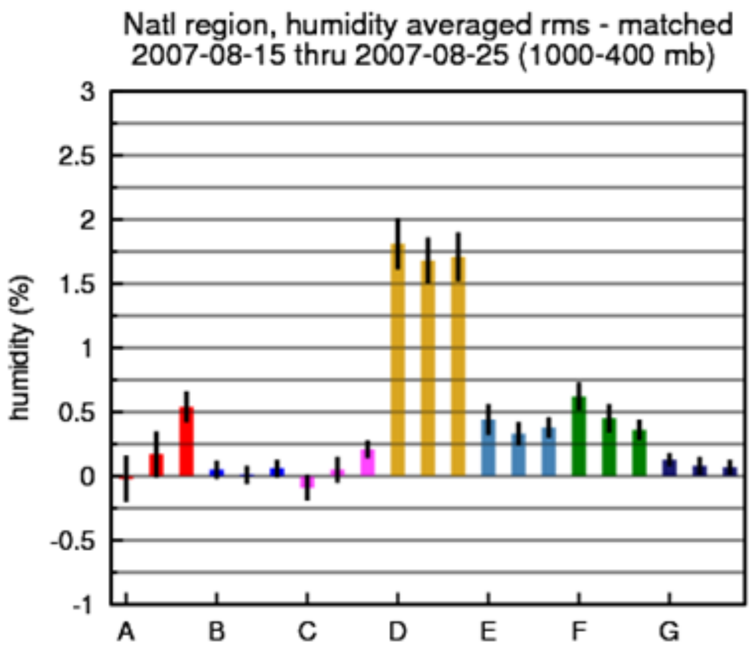


Data we denied:

a) aircraft / AMDAR
b) Profilers (NPN plus CAP)
c) VAD, from NEXRAD radars
d) RAOBs
e) GPS precipitable water
f) AMV (atmos motion vectors = sat. cloud-drift winds)
g) All surface (METARs plus mesonet)
h) METAR, color coded by altitude.

Each denial run was compared with a control run.
Forecast errors between runs were compared.





RH forecasts

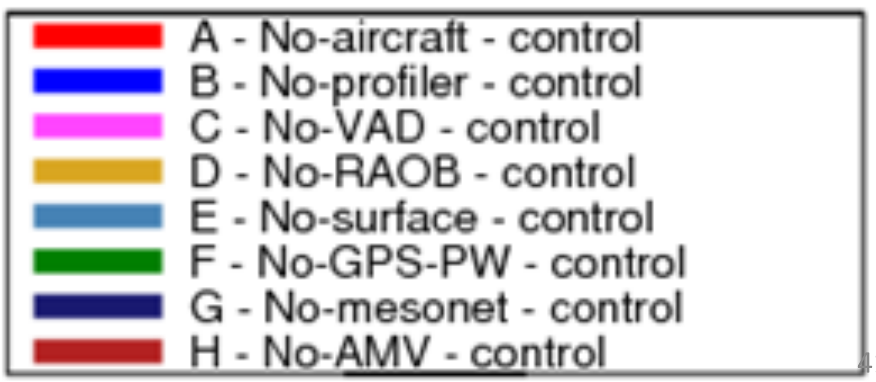
Bar height indicates impact

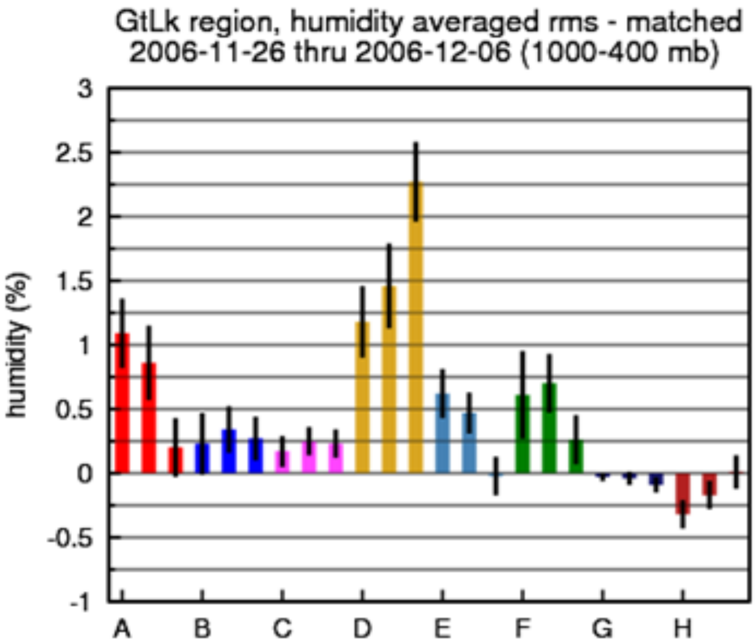
- Sfc - 400 hPa
- National region

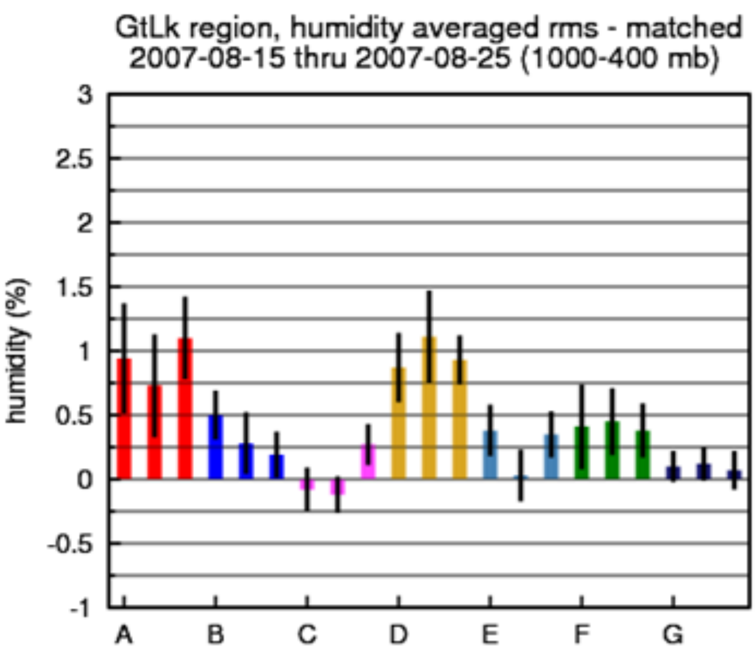
Groups: 3-h, 6-h, 12-h forecast for
each data type

Top: Winter
Bottom: Summer
Black bar: 1 std. error

- **RAOBs have most impact**
- **Then GPS-PW**
- **Then Aircraft/Surface**







RH forecasts

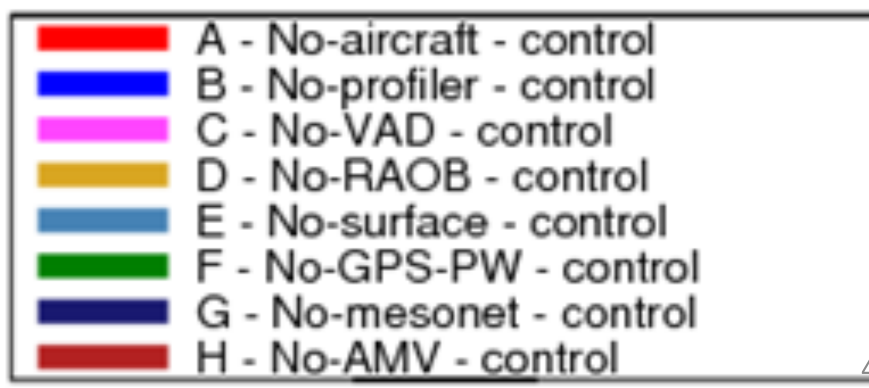
Now, *for the data-rich Great Lakes region.*

(Otherwise, as in previous slide)

- **RAOBs have most impact**
- **Then aircraft**

Increased aircraft impact reflects TAMDAR in the Midwest

- High data density
- RH measurements



Conclusions (1)

- **Each** of the heterogeneous data sources add value to RUC forecasts (under varying conditions)

- **TAMDAR** makes a positive and increasing contribution

- RUC/RR provide excellent platforms for performing Observation Sensitivity Experiments
  - (we have used the RR to evaluate the TAMDAR fleet flying in Alaska)

Conclusions (2)

- These RUC-based obs impact studies have led to operational changes
  - Three TAMDAR fleets are now **operational at NCEP, assimilated into RUC and NAM.**
  - New assimilation schemes are being implemented in the operational RUC
  - (The NWS has issued a procurement for a National Profiler Network, based in part on GSD's earlier studies of profiler impact.)
- This work has also resulted in a *development verification infrastructure* that has been critical for refining the RUC, RR, and FIM.

Rapid Refresh / RUC Technical Review - OUTLINE

1:30 – 1:45	RUC➔RR transition overview, NCEP RUC changes – 2008-09-	Stan Benjamin
1:45 – 2:00	Observation impact experiments - TAMDAR aircraft obs w/ moisture, larger OSE	Bill Moninger
2:00 – 2:20	Rapid Refresh overview, assimilation –	Steve Weygandt, Ming Hu
2:20 – 2:30	-- Break --	
2:30 – 3:05	RR-WRF model development / testing – physics, cloud, chemistry, PBL	John Brown, Tanya Smirnova, Joe Olson
3:05 – 3:20	The HRRR and HCPF (HRRR prob forecast)	Curtis Alexander
3:20 – 3:30	Future of RR/HRRR/ens	Stan Benjamin

Background on Rapid Refresh, why replace the RUC?

- **More advanced model and analysis systems**

  - WRF-ARW: advanced numerics, non-hydrostatic
  - GSI: advanced satellite assim, 4DVAR development
  - Both community-based, ongoing code contributions

- **Domain expansion for consistent guidance**

  - Hourly-updating for Alaska, Caribbean users
  - Consistent input for aviation hazard guidance products over all of North America
  - Uniform, hourly-updated guidance for RTMA

RUC to Rapid Refresh

• **CONUS domain (13km)**	• **North American domain (13km)**
• **RUC 3DVAR**	• **GSI (Gridpoint Statistical Interpolation)** (incl. RR enhancements)
• **RUC model + postprocessing**	• **WRF-ARW model (RR version) + WRFpost (with enhancements)**

RUC to Rapid Refresh

- **CONUS domain (13km)** → **North American domain (13km)**
- **RUC 3DVAR** → **GSI (Gridpoint Statistical Interpolation)** (incl. RR enhancements)
- **RUC model + postprocessing** → **WRF-ARW model (RR version) + WRFpost (with enhancements)**

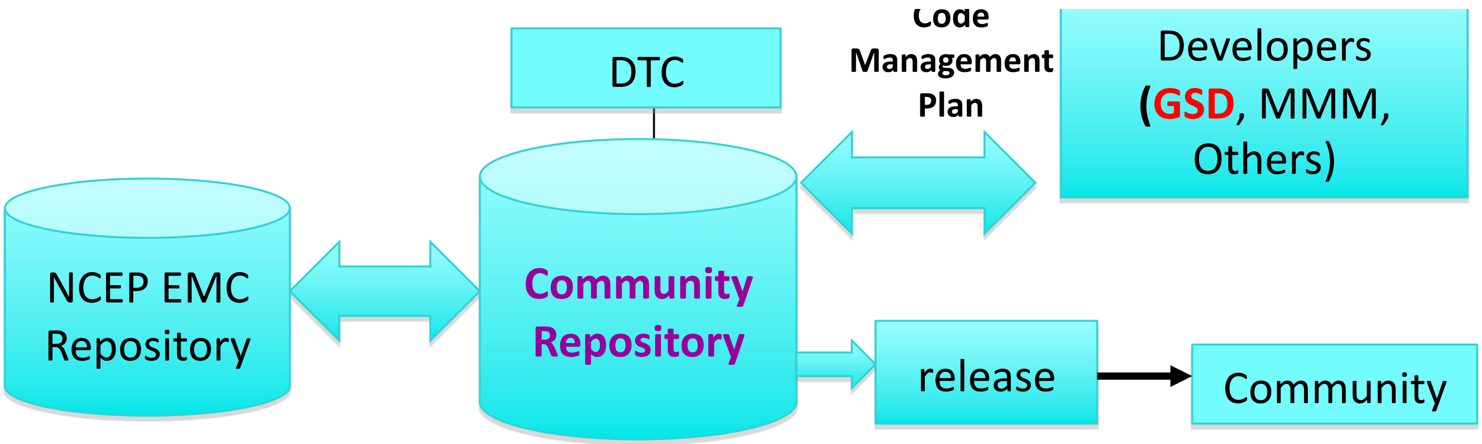
Background on GSI, why use it for Rapid Refresh?

- **NCEP, NASA GMAO supported "full" system**
  - Developed from global Spectral Statistical Interpolation
  - Advanced satellite radiance assimilation with JCSDA
  - NASA GMAO work to create GSI-based 4DVAR
- **Evolution toward community analysis system**
  - GSI used by NCEP for GFS and NAM
  - Selection of GSI as analysis for RR (2005)
  - Use of GSI obs processing for ESRL EnKF work
  - Transition to GSI by Air Force Weather Agency
  - DTC work to make GSI available to research community
  - Evolution to community-wide SVN code management

Community GSI Code Repository

Boulder Community GSI Code Management Plan

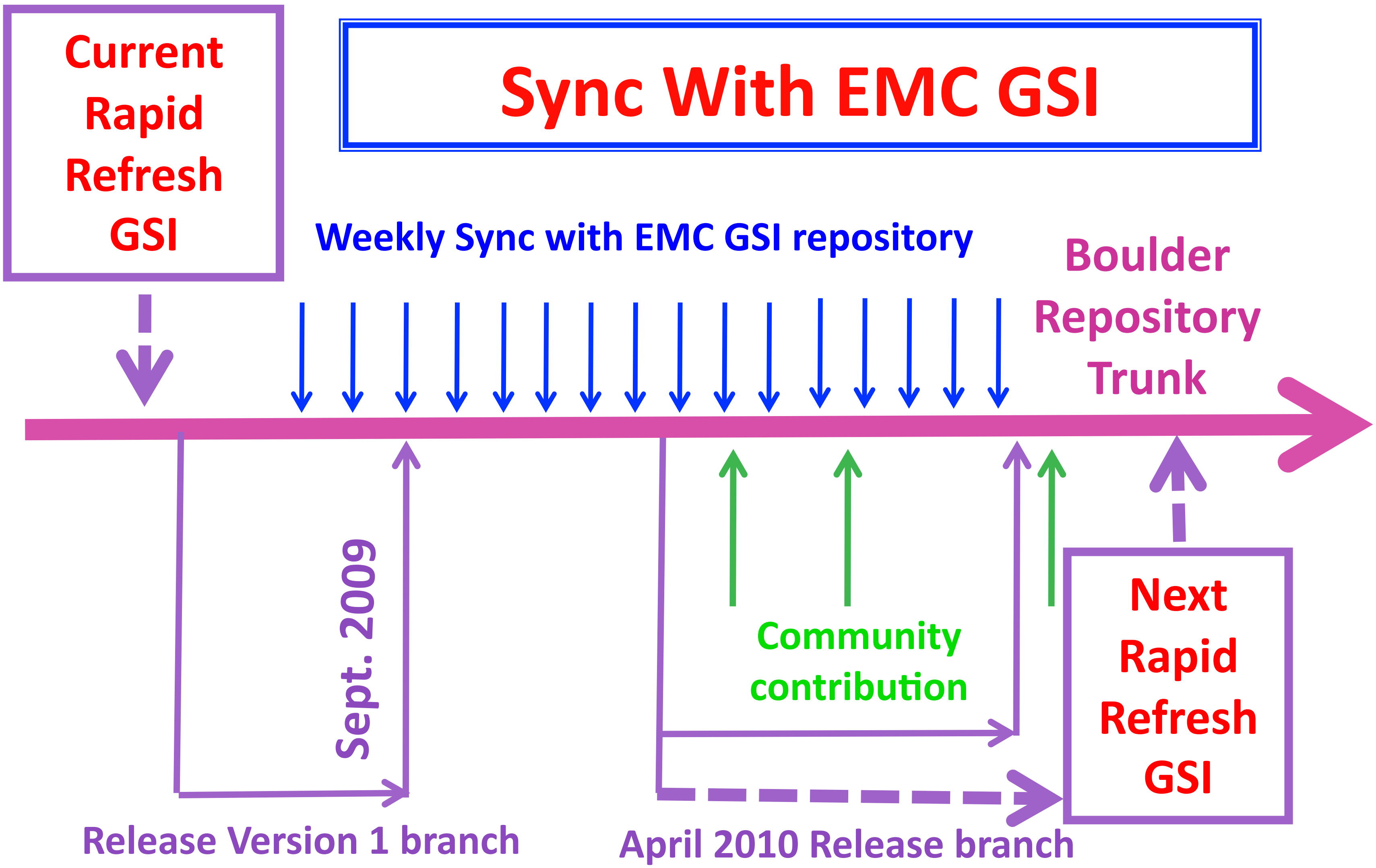
Draft 09/02/2009



GSD - build and maintain server

https://gsi.fsl.noaa.gov/svn/comgsi/trunk

Sync With EMC GSI



Significant AMB contribution:
porting to Linux,
coupling with ARW

DTC lead: porting & testing
AMB focus: special RR features
(cloud analysis, etc.)

ESRL and DTC work with GSI

- **Porting of GSI to from NCEP IBM to ESRL Linux**
  - Many IBM-specific coding features, especially I/O
  - Much work by ESRL IT team to get robust Linux GSI
  - Excellent DTC leadership in code testing, management
- **Coupling of GSI to WRF ARW**
  - Testing and evaluation of many GSI features for ARW
  - Completion of several GSI ARW code stubs
  - Adaptation of GSI and ARW modules to accommodate hourly cycling

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Adding Rapid Refresh specific features to GSI

Introducing RR features into GSI

Hourly update cycle
- switch to partial cycling
- Use of observations (NCEP prepBUFR + satellite data)
- Satellite bias corrections (from NCEP)

Cloud analysis
- Uses METAR, satellite, radar data
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Radar reflectivity assimilation
- Apply LH in diabatic digital filter initialization

Surface observation assimilation -- ongoing
- Account for model vs. terrain height difference
- Apply surface observation innovations through PBL
- Select best background for coastal observations

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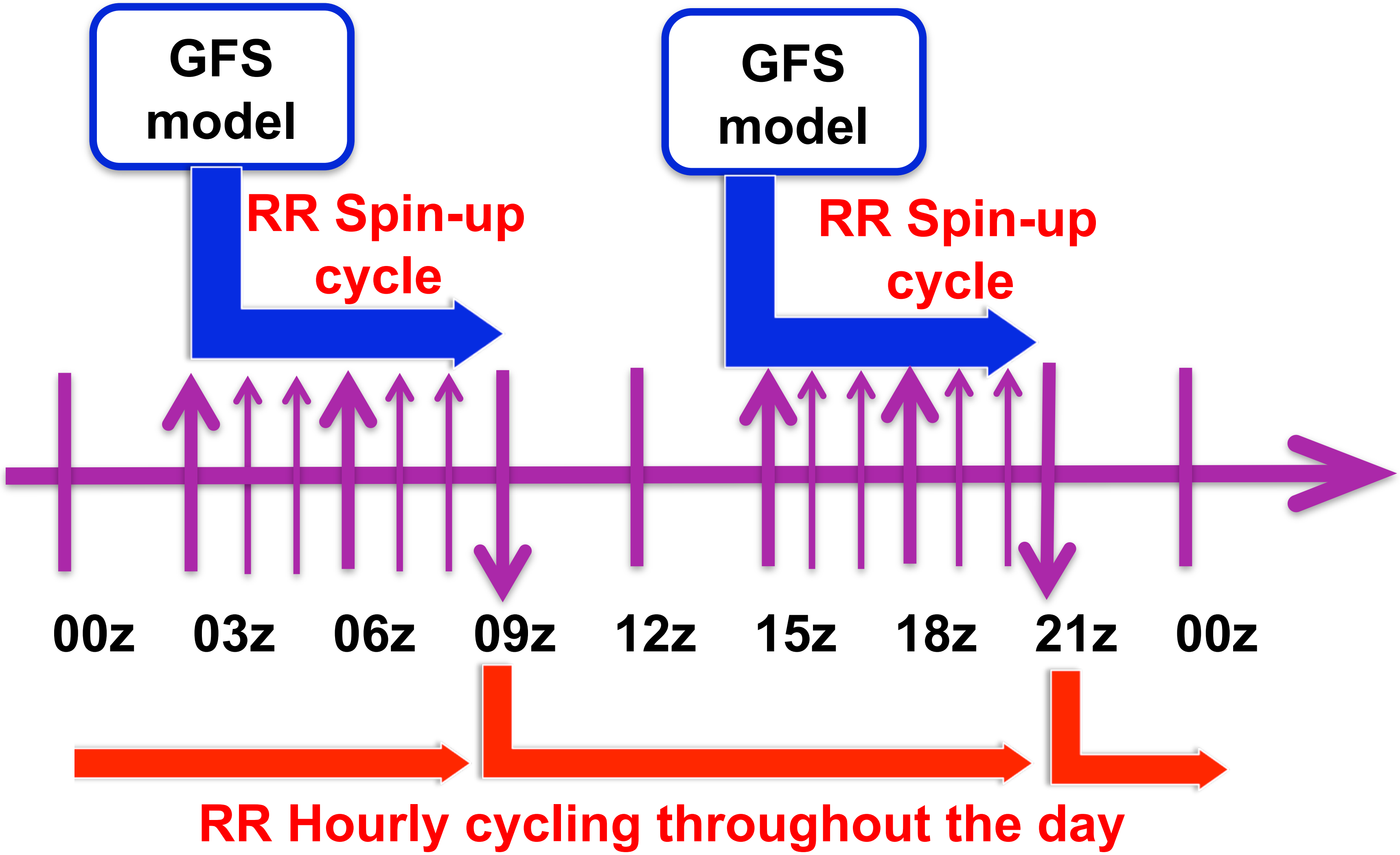
Rapid Refresh Partial Cycling



- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields

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RUC/RR cloud / radar assimilation flowchart

RUC/RR cloud / radar assimilation flowchart

1-h fcst
qv, qc, qi,
qr, qs, qg

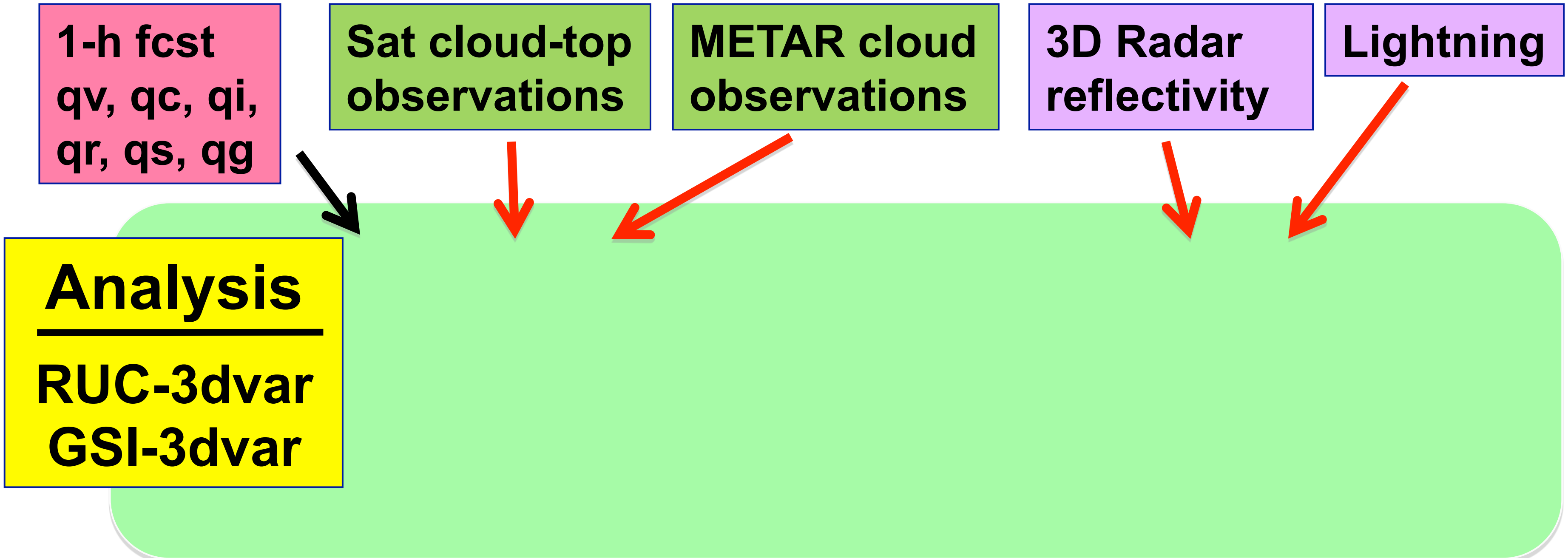
Sat cloud-top
observations

METAR cloud
observations

3D Radar
reflectivity

Lightning

RUC/RR cloud / radar assimilation flowchart



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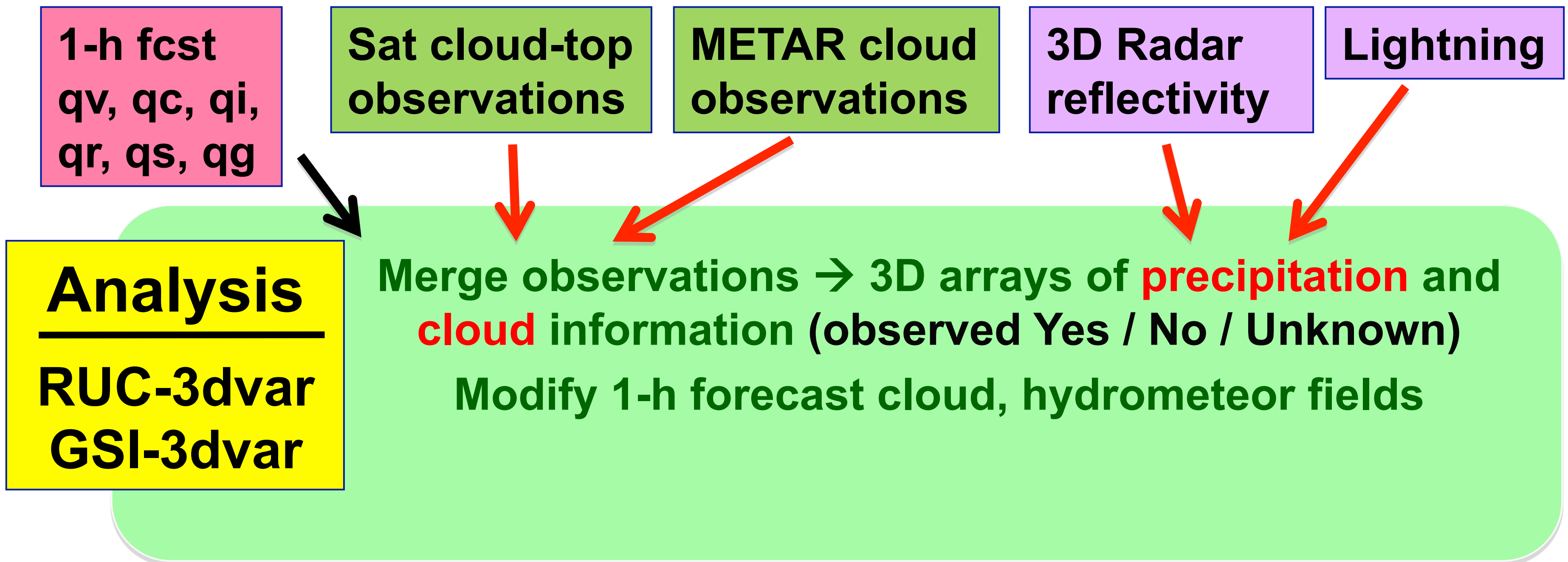

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1-h fcst
qv, qc, qi,
qr, qs, qg

Sat cloud-top
observations

METAR cloud
observations

3D Radar
reflectivity

Lightning

Analysis

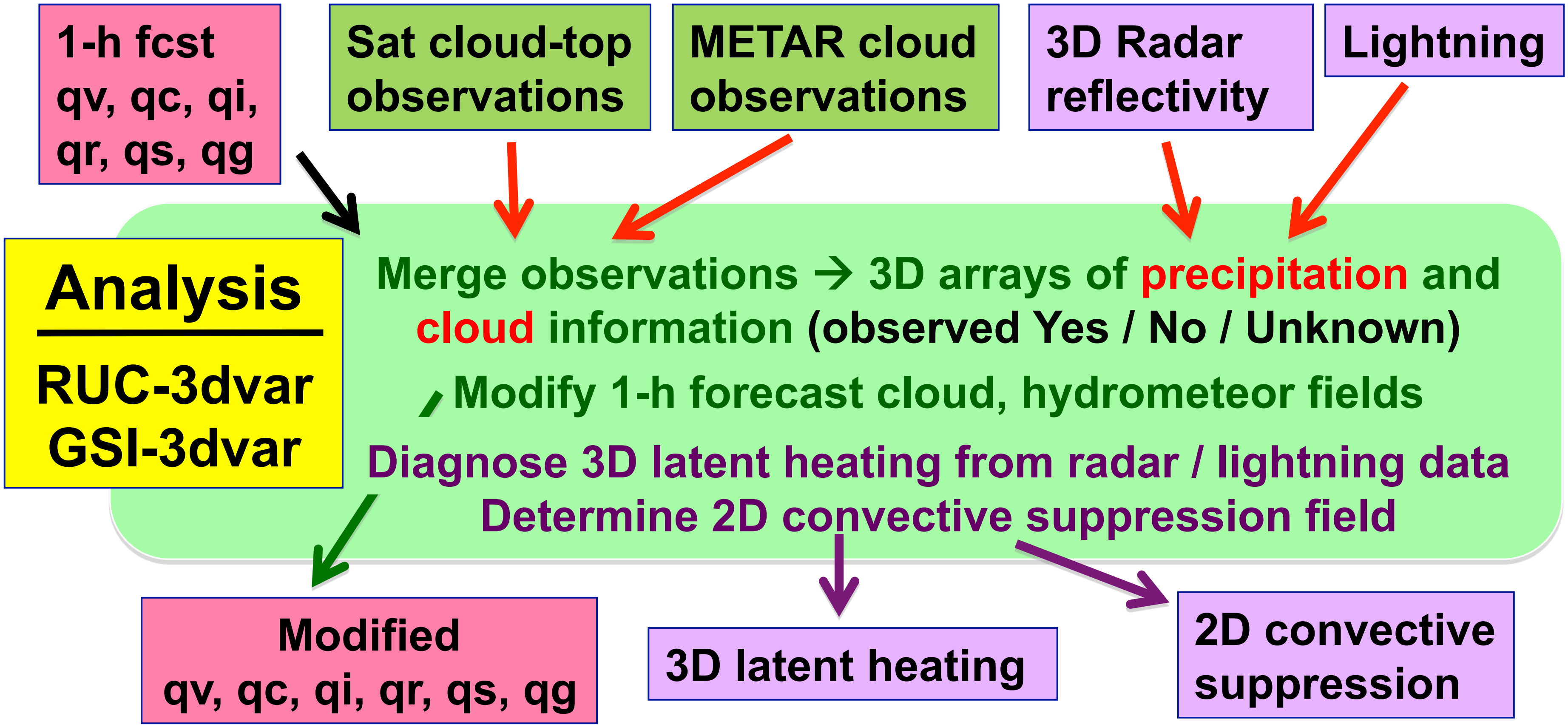
RUC-3dvar
GSI-3dvar

Merge observations → 3D arrays of precipitation and cloud information (observed Yes / No / Unknown)

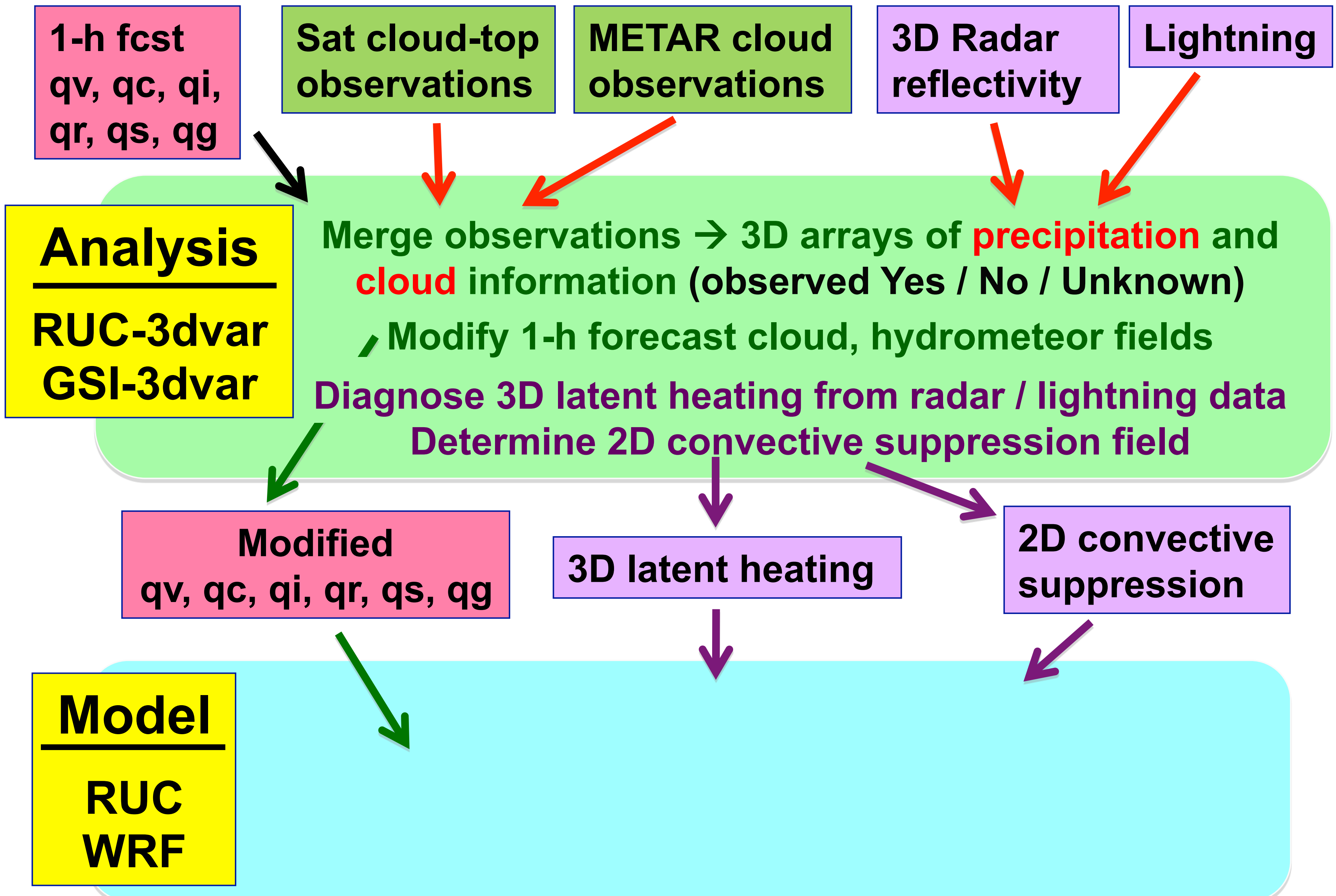
Modify 1-h forecast cloud, hydrometeor fields

Diagnose 3D latent heating from radar / lightning data
Determine 2D convective suppression field

RUC/RR cloud / radar assimilation flowchart



RUC/RR cloud / radar assimilation flowchart



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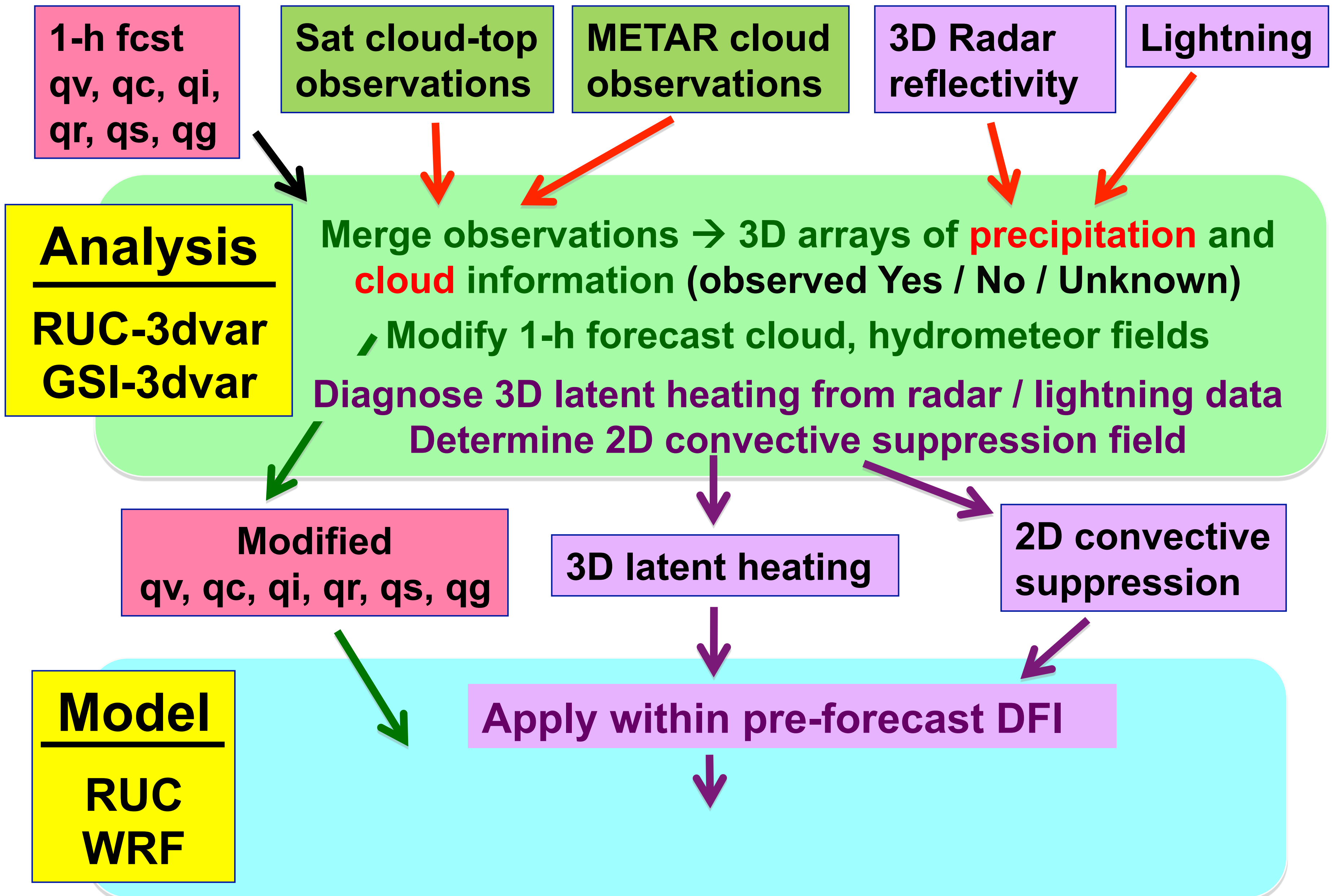
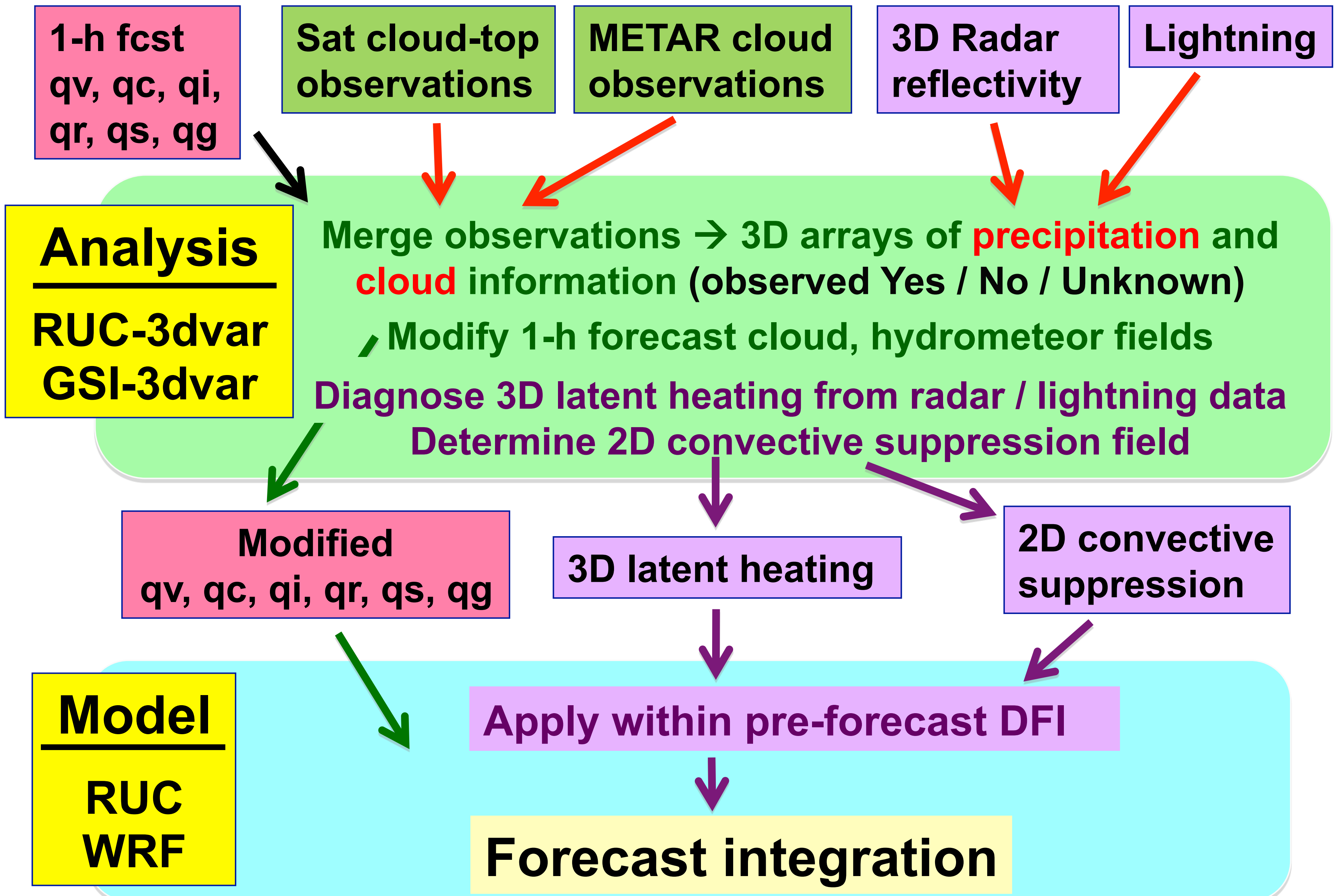
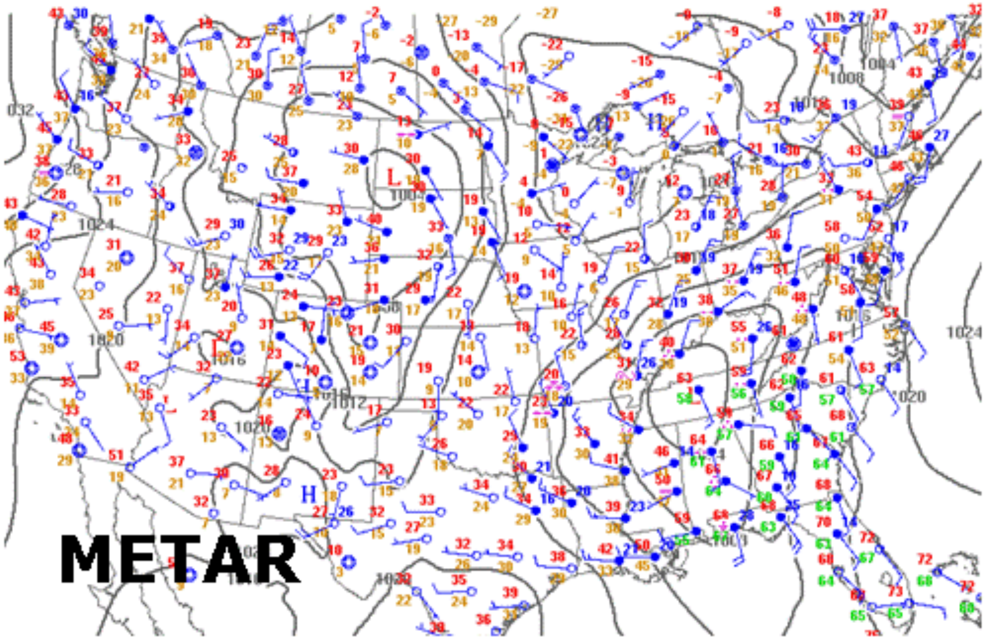


RUC/RR cloud / radar assimilation flowchart

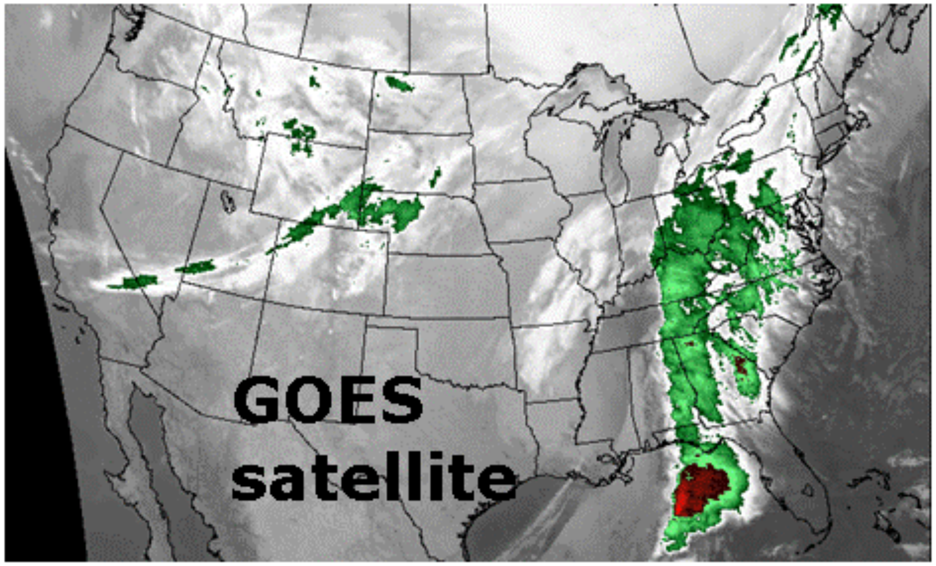


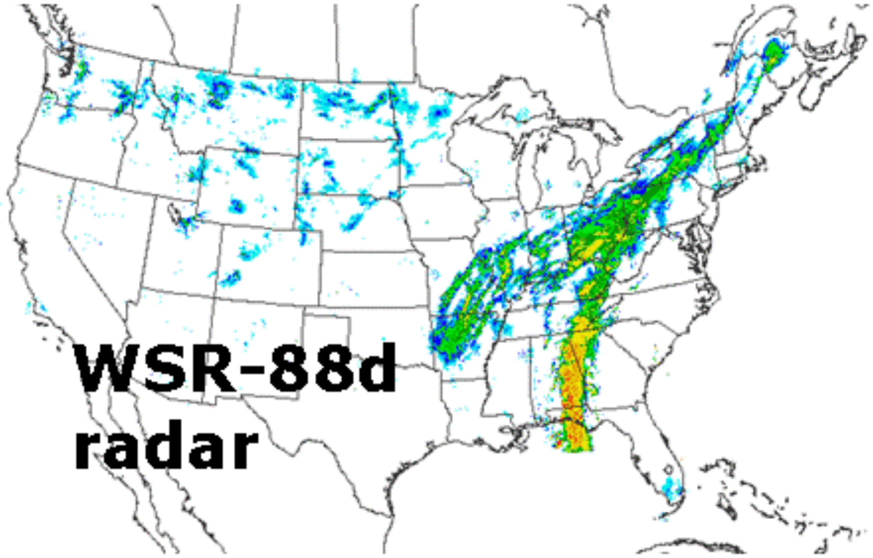
Cloud Observations from three sources



Combine with 1h fcst - 3-d fields of qc, qi, qr, qs, qg

12 UTC 4 March 2008

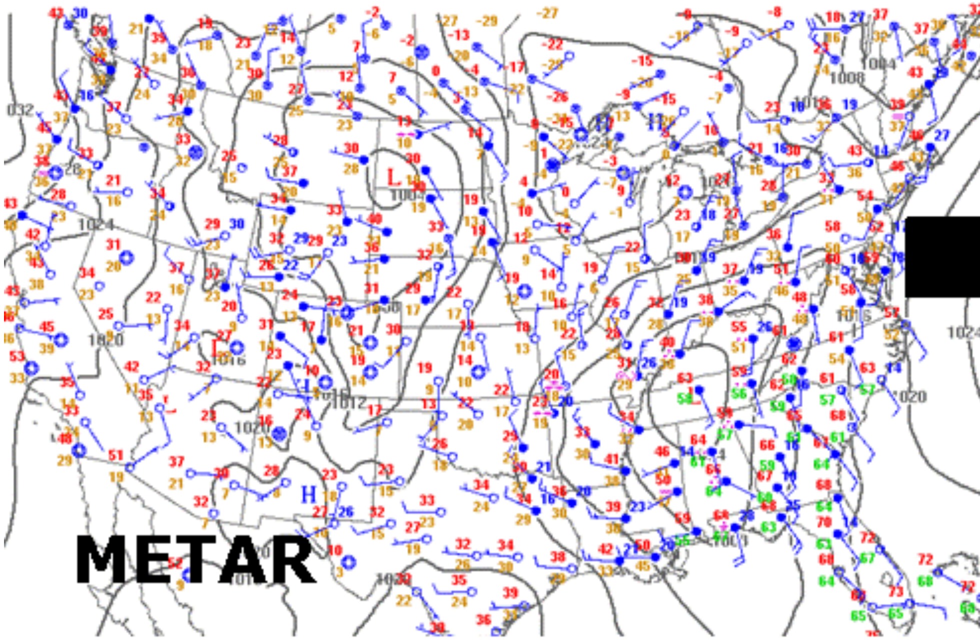




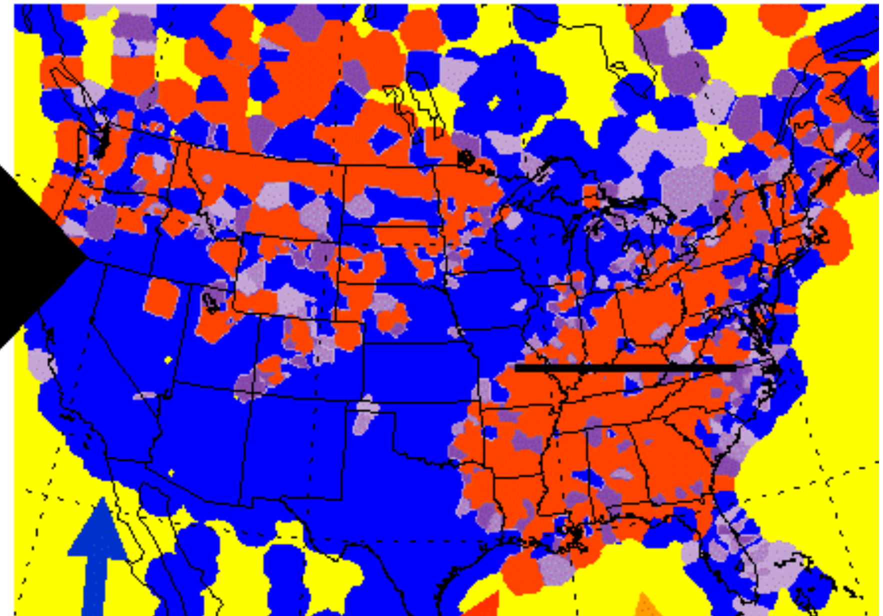
Processing METAR observations

Column "maximum" cloud

Yes > No > Unknown



12 UTC 4 March 2008



NO clouds

YES clouds

OVC

BKN

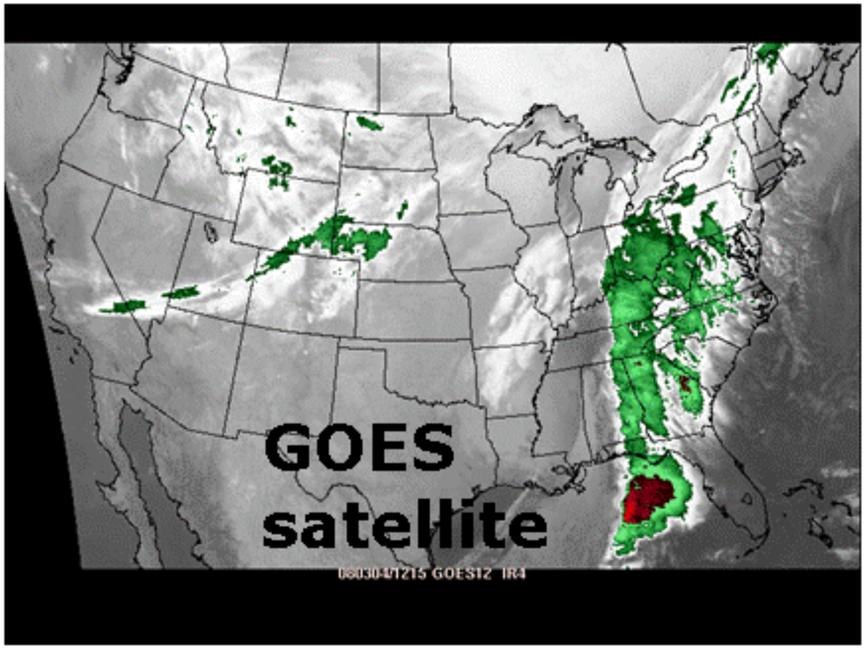
SCT

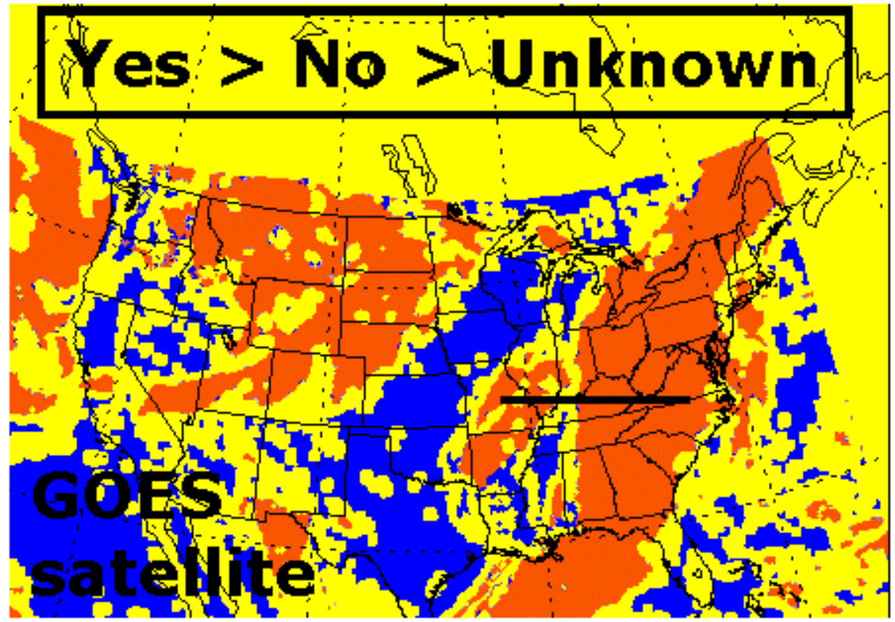
UNKNOWN clouds

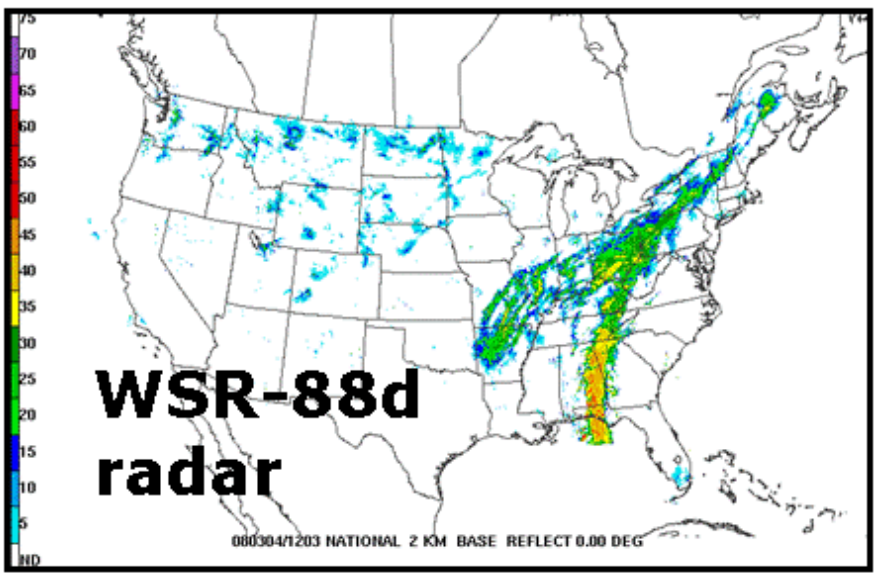
Cloud designation from observations

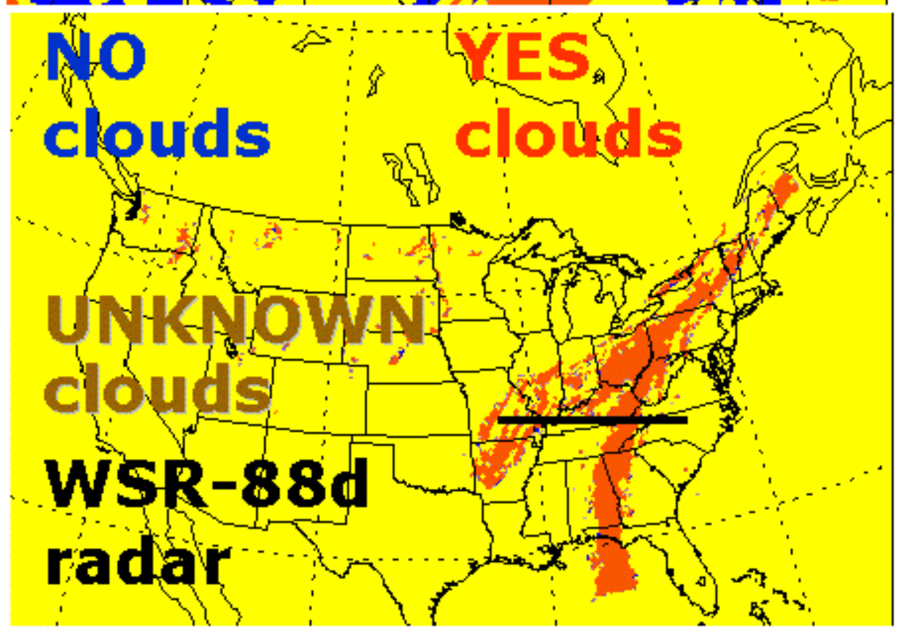
Specify 3-dimensional Yes/No/Unknown field

Observations → Column "maximum" cloud

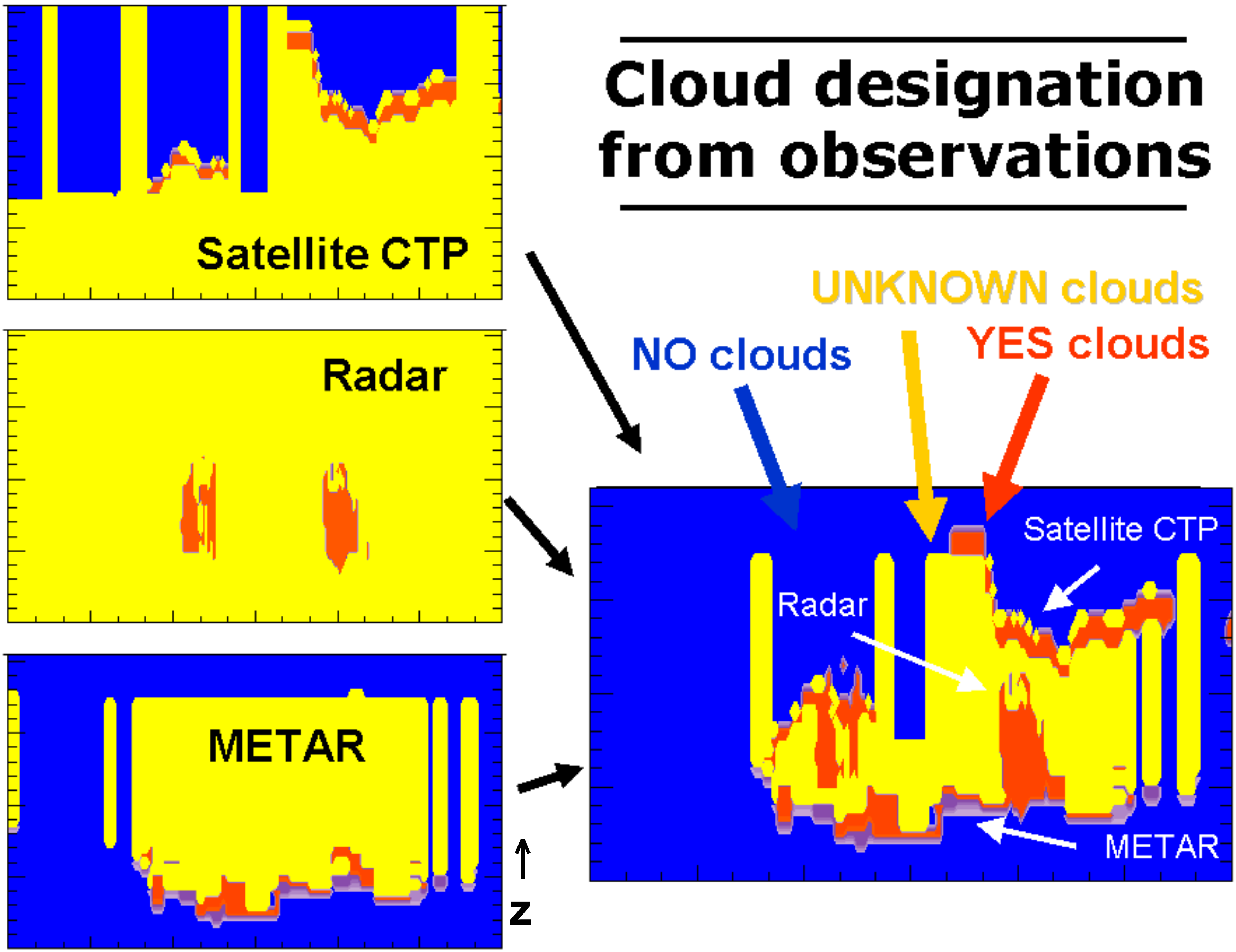




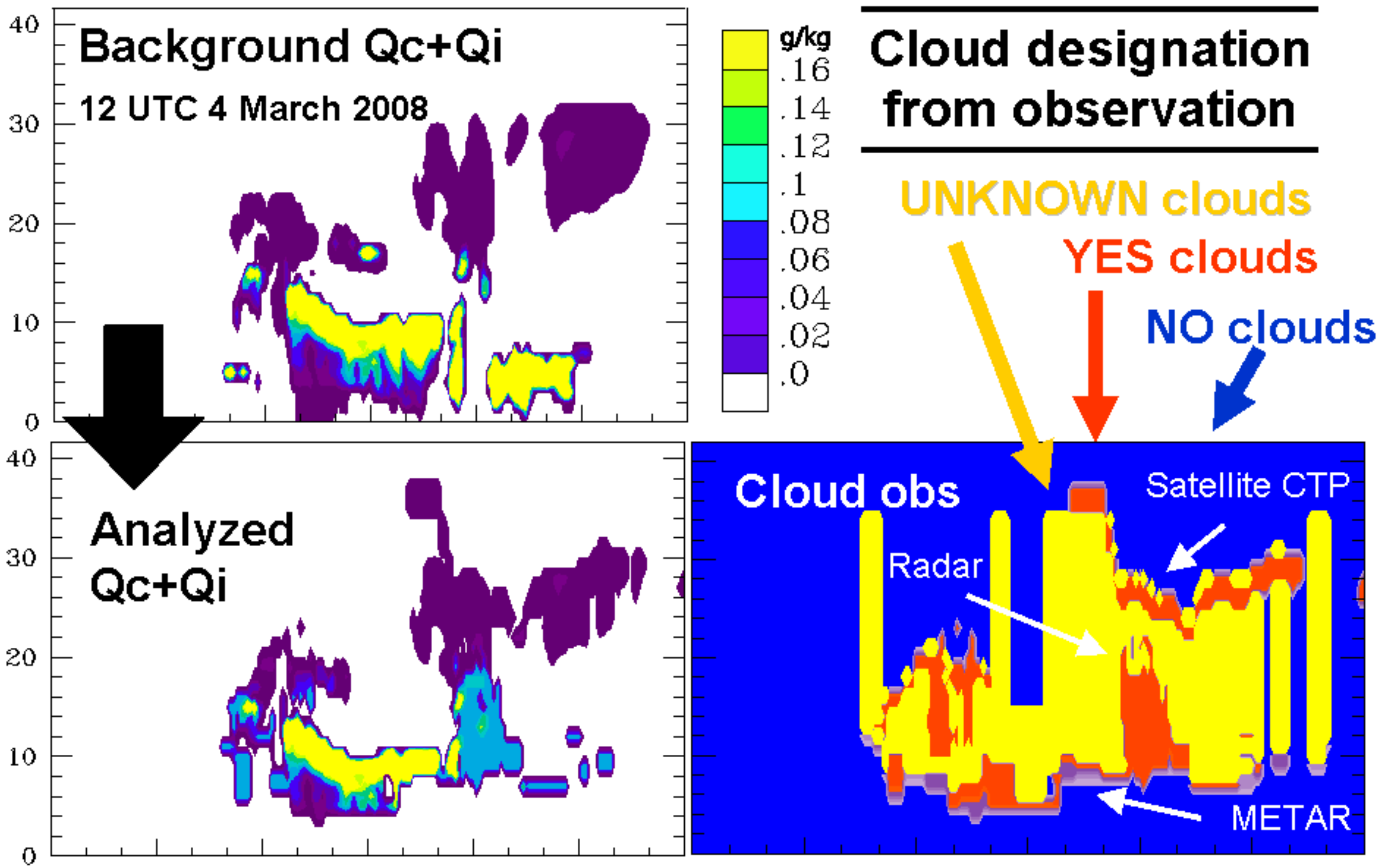




Cloud designation from observations

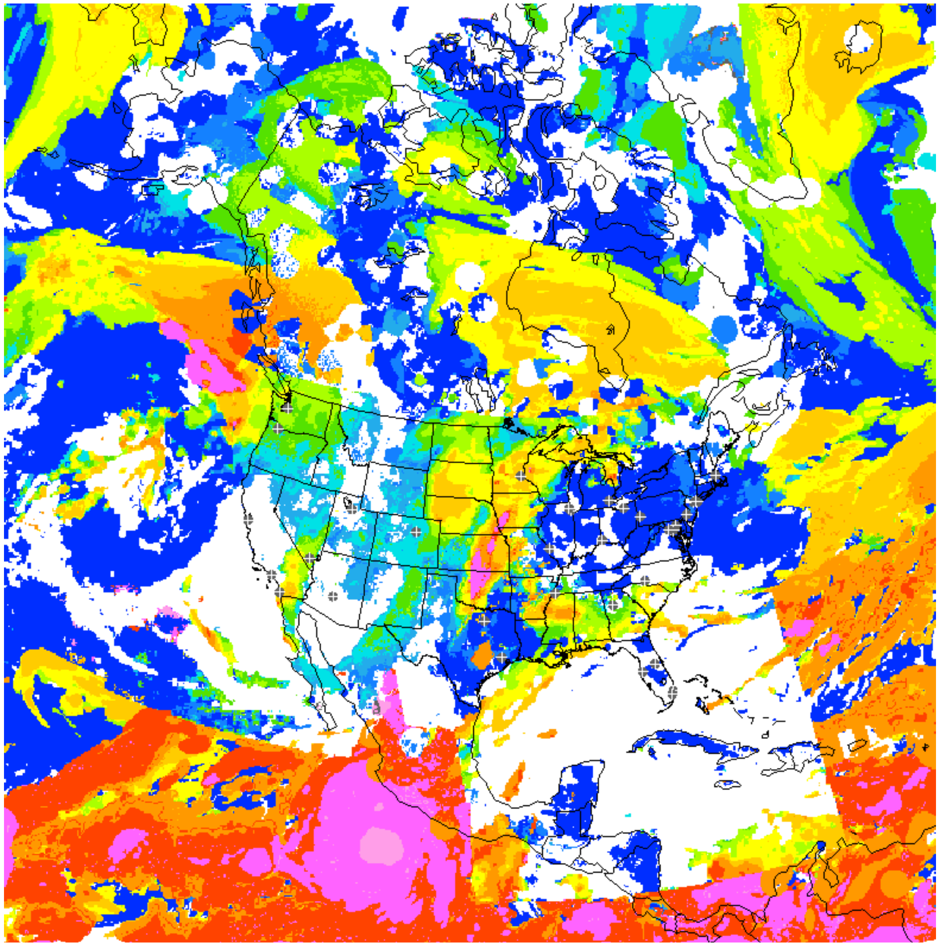


Modify background with cloud observations

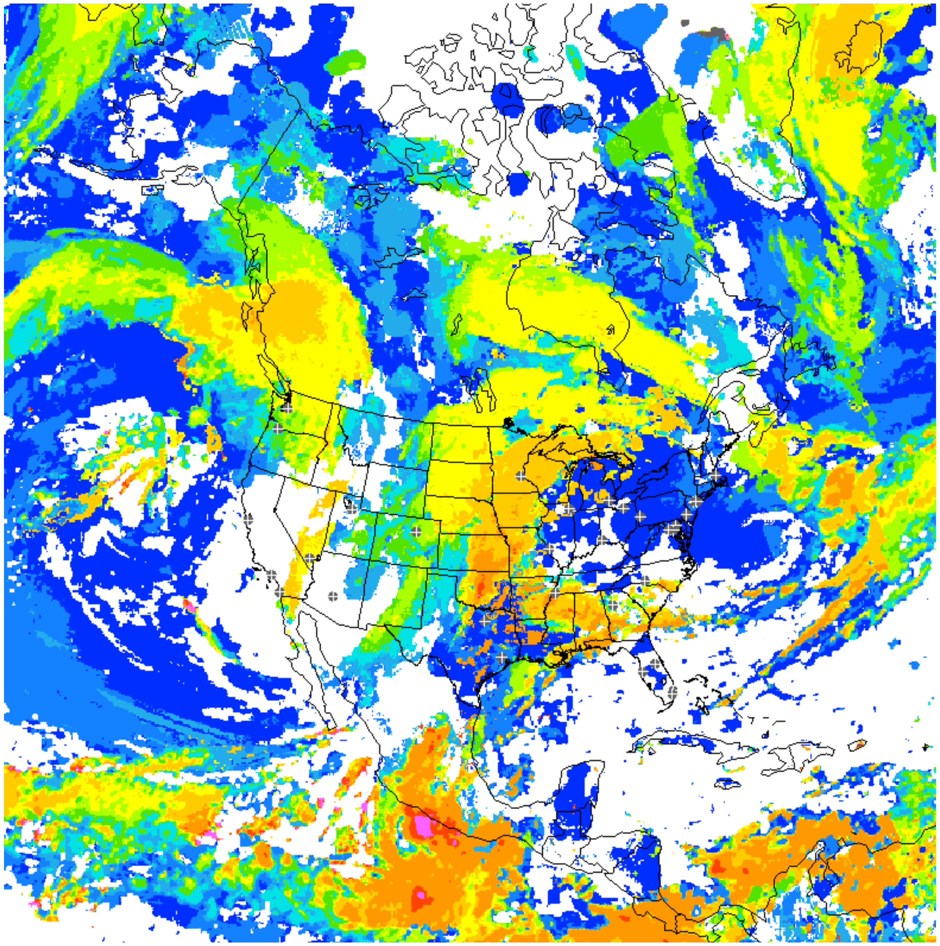


Use of NASA Langley satellite cloud data

RR with NESDIS data- only over RUC domain



RR with NASA data - over full RR domain



Analysis

Introducing RR features into GSI

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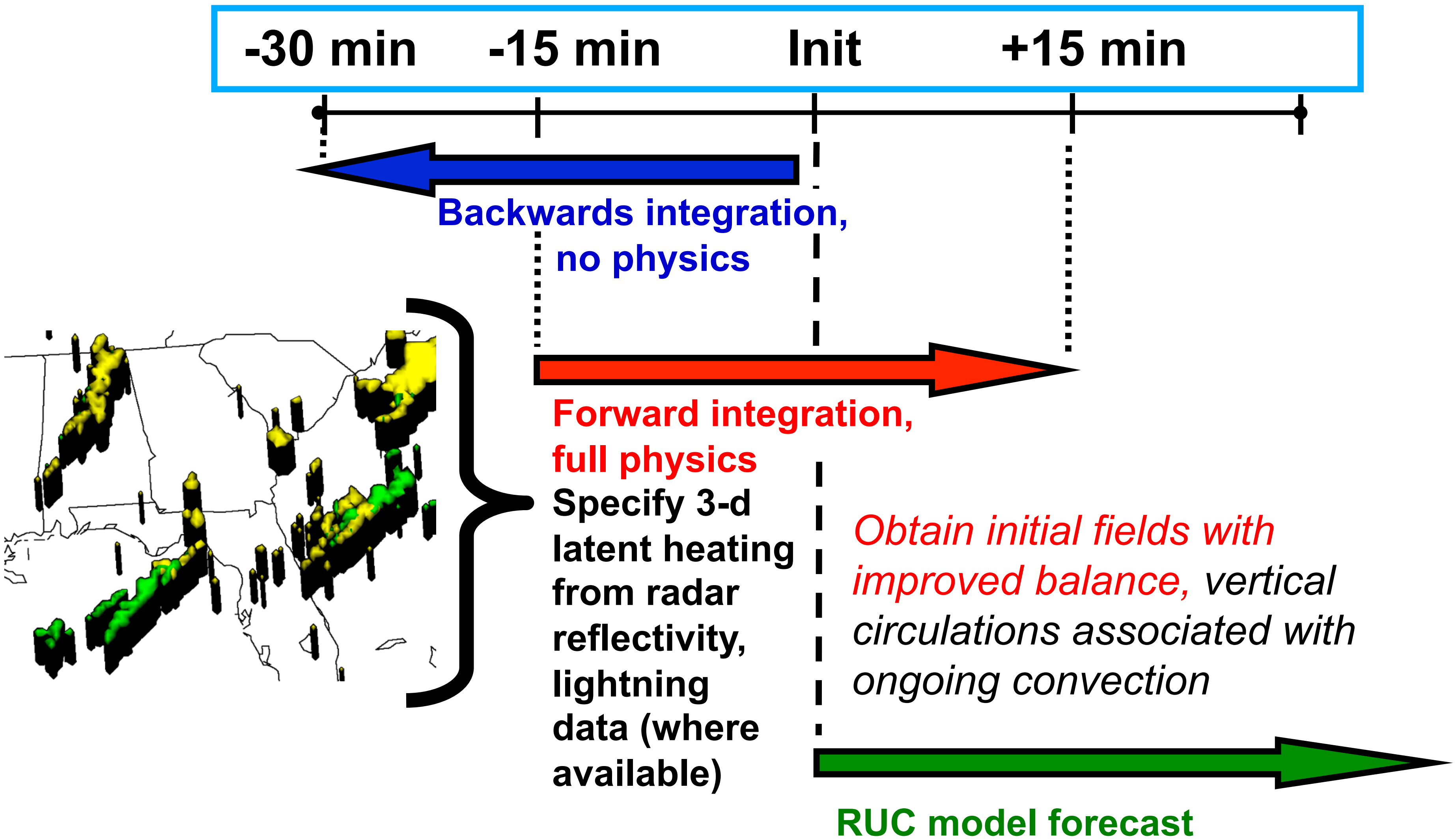
RUC / RR Diabatic Digital Filter Initialization (DDFI)

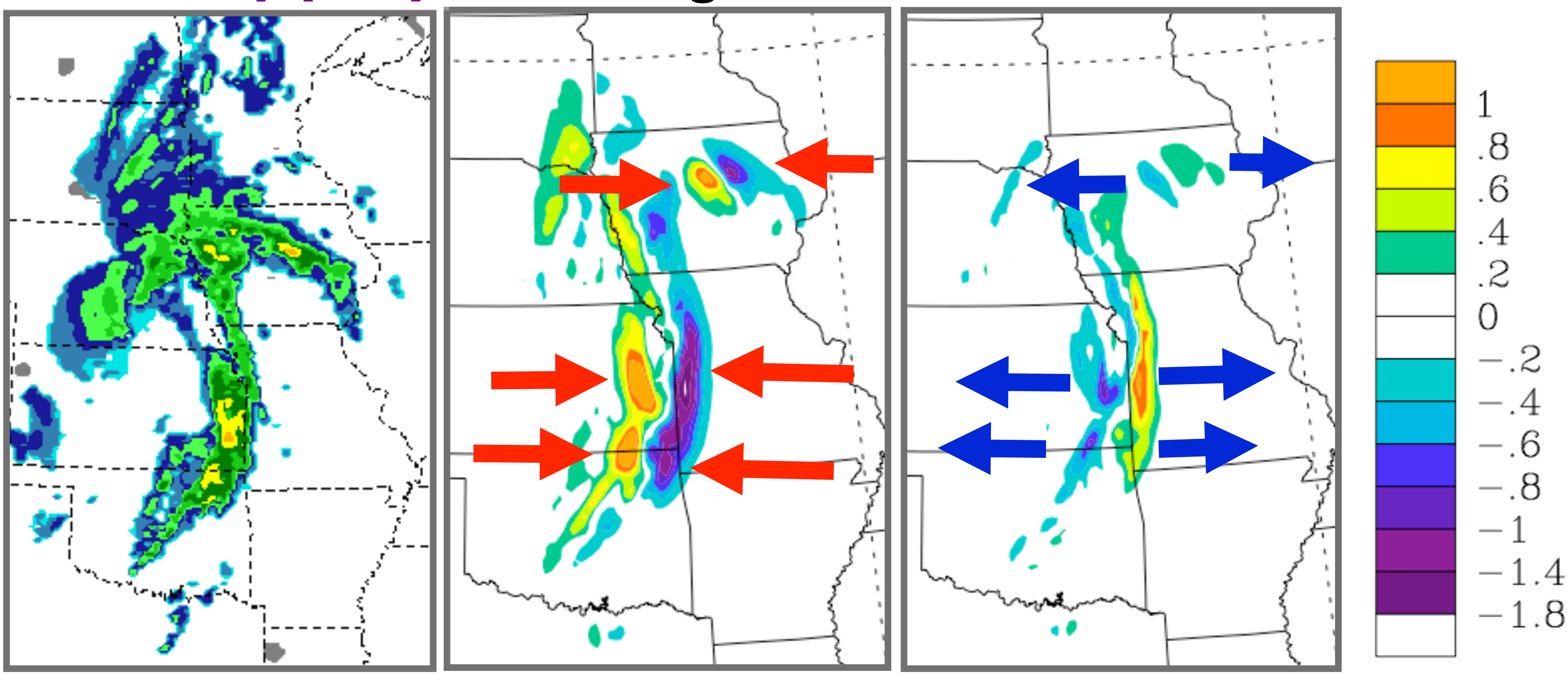
New - add assimilation of radar data



Radar reflectivity assimilation in RUC and Rapid Refresh

Rapid Refresh (GSI + ARW) reflectivity assimilation example

NSSL radar reflectivity (dBZ) | Low-level Convergence | Upper-level Divergence



14z 22 Oct 2008
Z = 3 km

K=4 U-comp. diff
(radar - norad)

K=17 U-comp. diff
(radar - norad)

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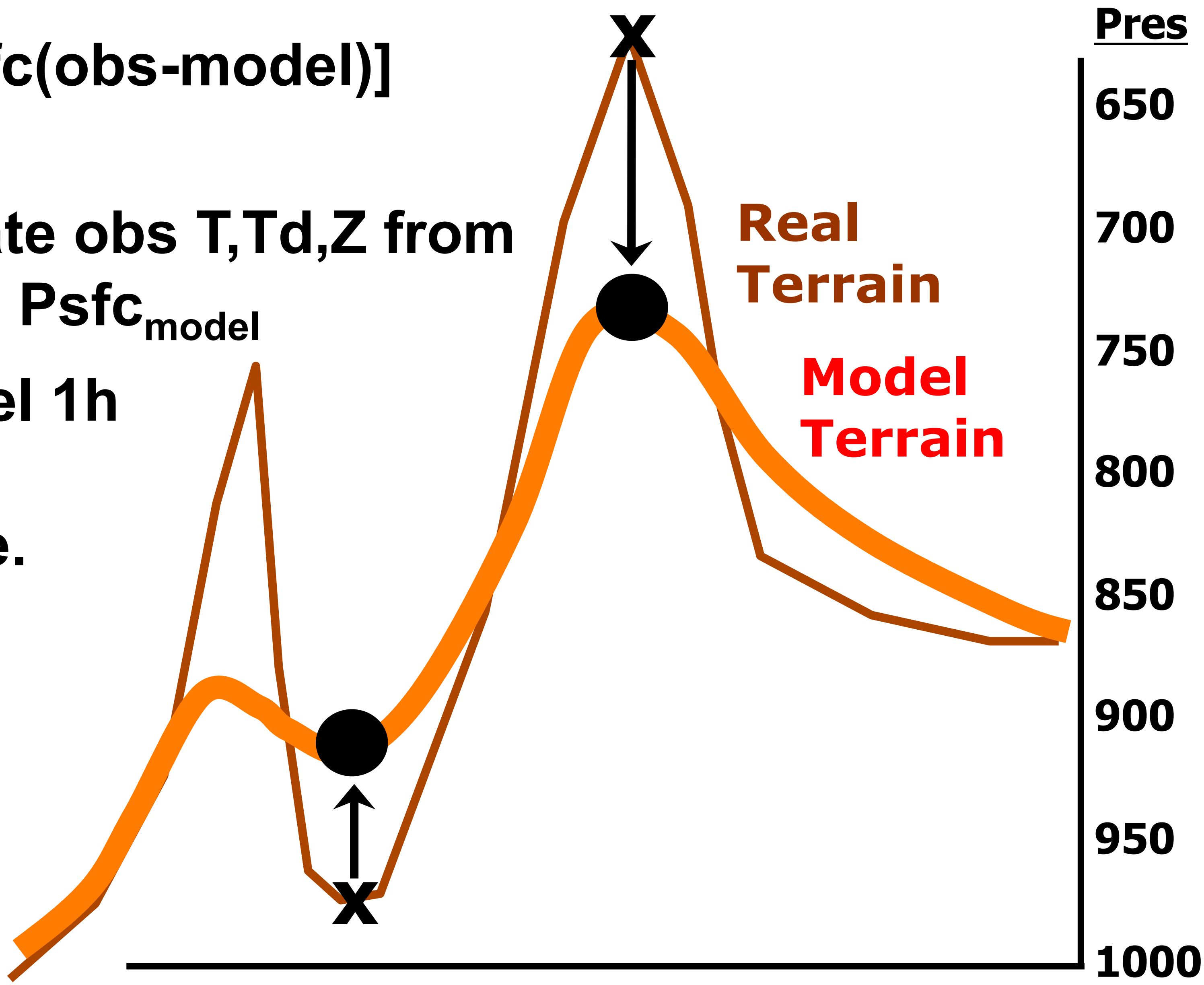
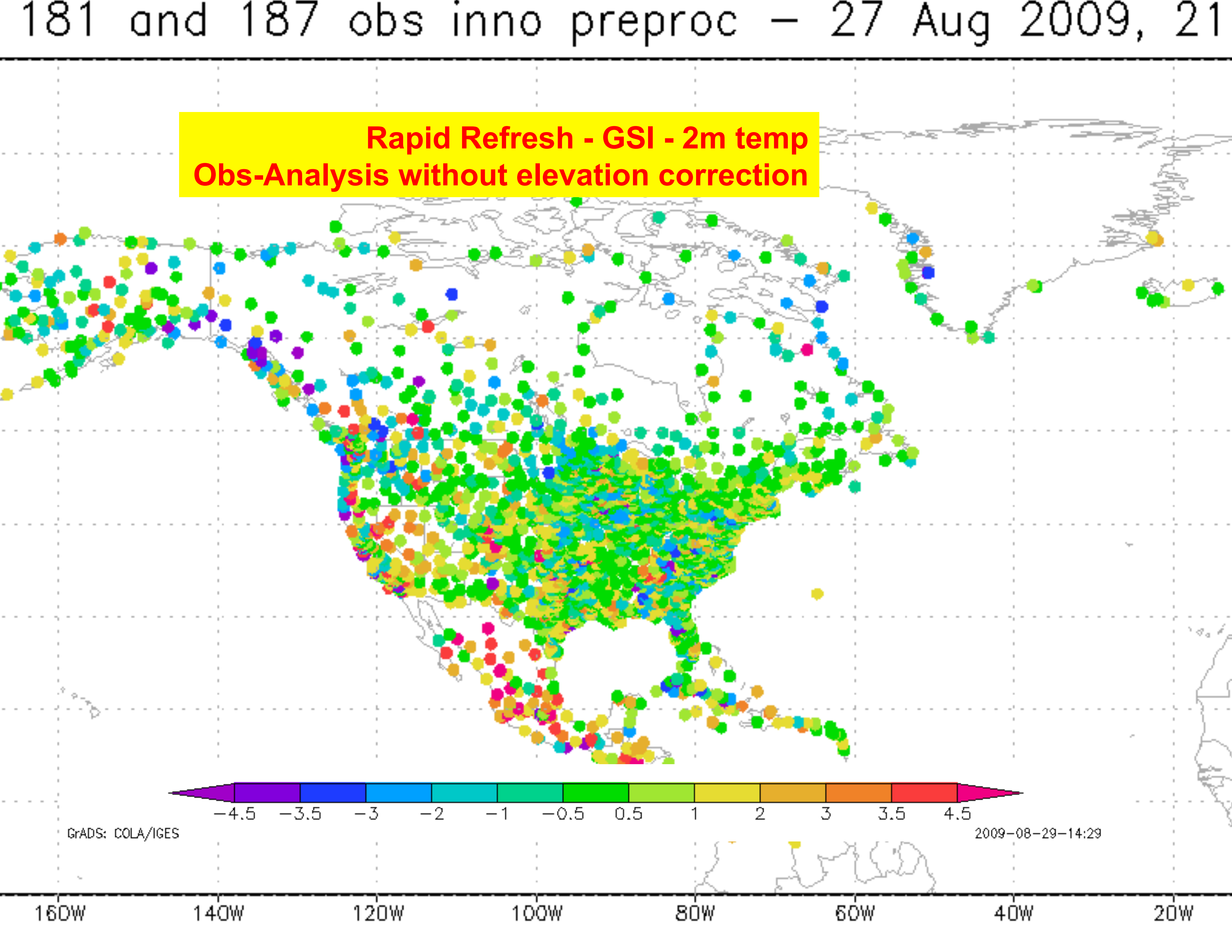
Elevation correction (RUC/RR)

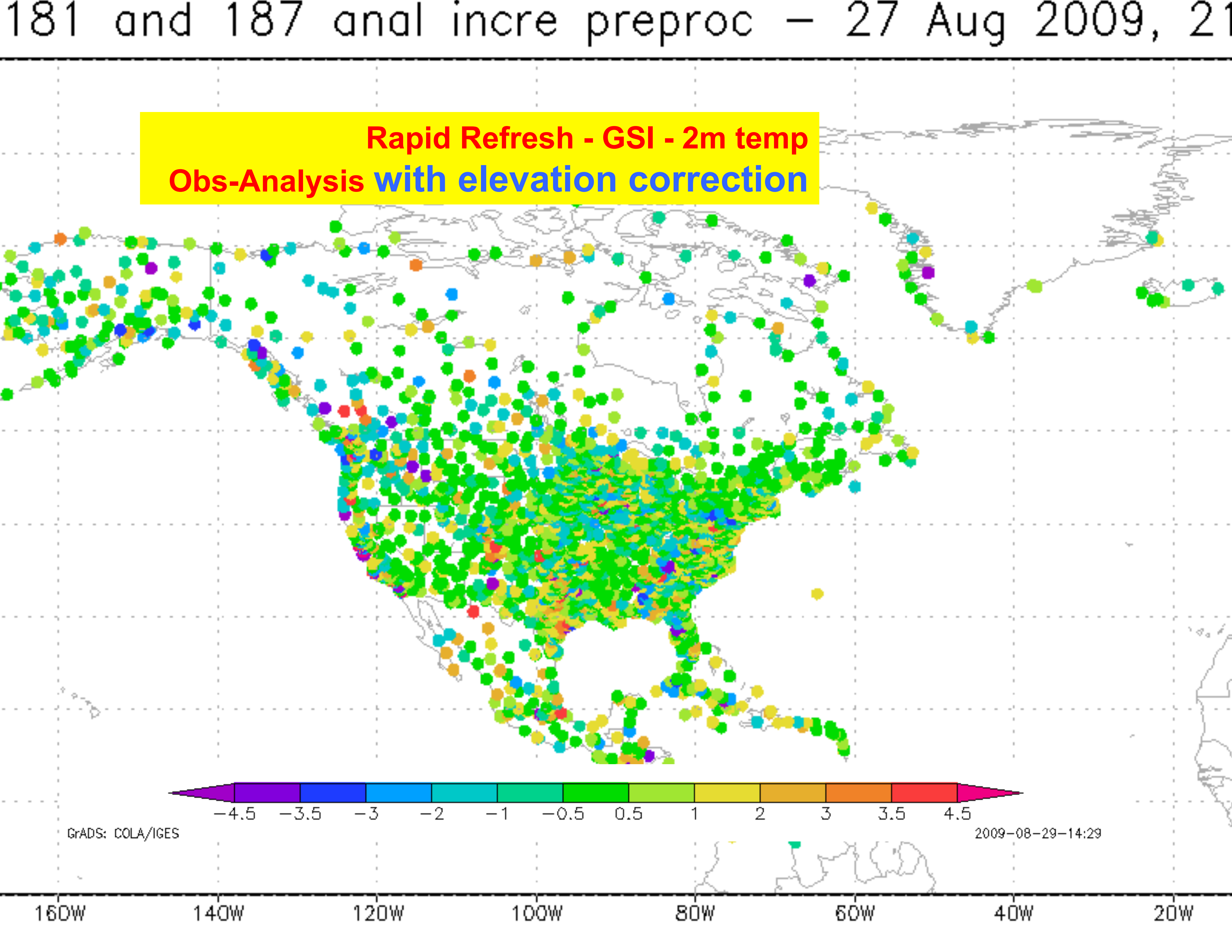
If abs[Psfc(obs-model)] < 70 hPa.

Extrapolate obs T,Td,Z from $Psfc_{obs}$ to $Psfc_{model}$

Use model 1h low-level lapse rate.




181 and 187 obs inno preproc – 27 Aug 2009, 21
Rapid Refresh - GSI - 2m temp
Obs-Analysis without elevation correction
−4.5
−3.5
−3
−2
−1
−0.5
0.5
1
2
3
3.5
4.5
GrADS: COLA/IGES
2009-08-29-14:29
160W
140W
120W
100W
80W
60W
40W
20W



181 and 187 anal incre preproc – 27 Aug 2009, 21
Rapid Refresh - GSI - 2m temp
Obs-Analysis with elevation correction
−4.5 −3.5 −3 −2 −1 −0.5 0.5 1 2 3 3.5 4.5
GrADS: COLA/IGES
2009-08-29-14:29
160W 140W 120W 100W 80W 60W 40W 20W

Verification (RR vs. RUC)

Upper-air

- Verify against rawinsonde
- Use native level data at 10 mb intervals

  Major improvement from partial cycling

Surface

- Verify against METAR obs for T, Td, wind, ceiling, visibility
- **Surface skill dependent on:**

  data assimilation

  model physics (BL, radiation)

  model post-processing

  RR skill similar RUC

Precipitation verification

- Verify against Stage 4

  RR similar skill, somewhat higher bias

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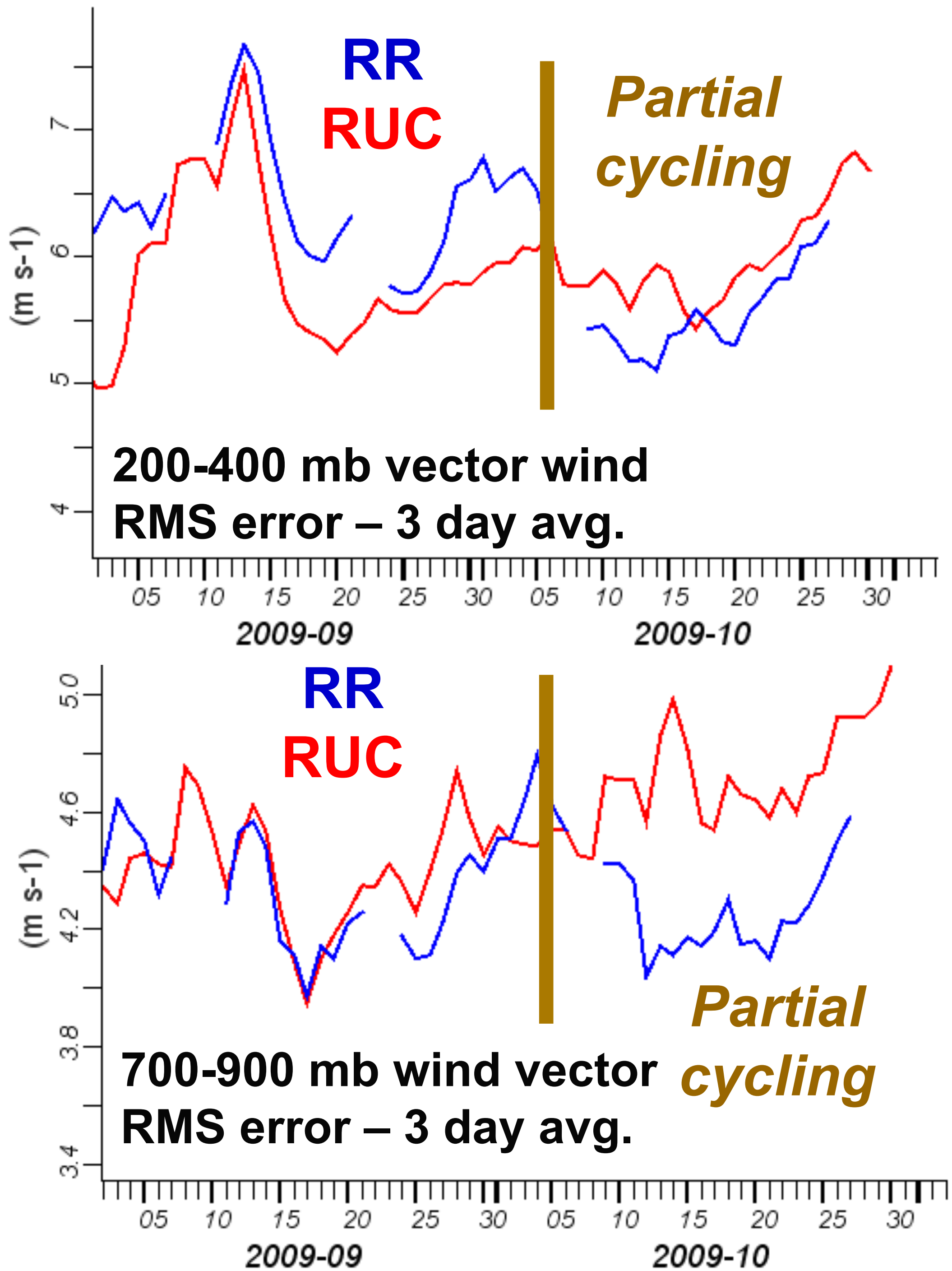
Rapid Refresh Upper-Air verification

Before partial cycling

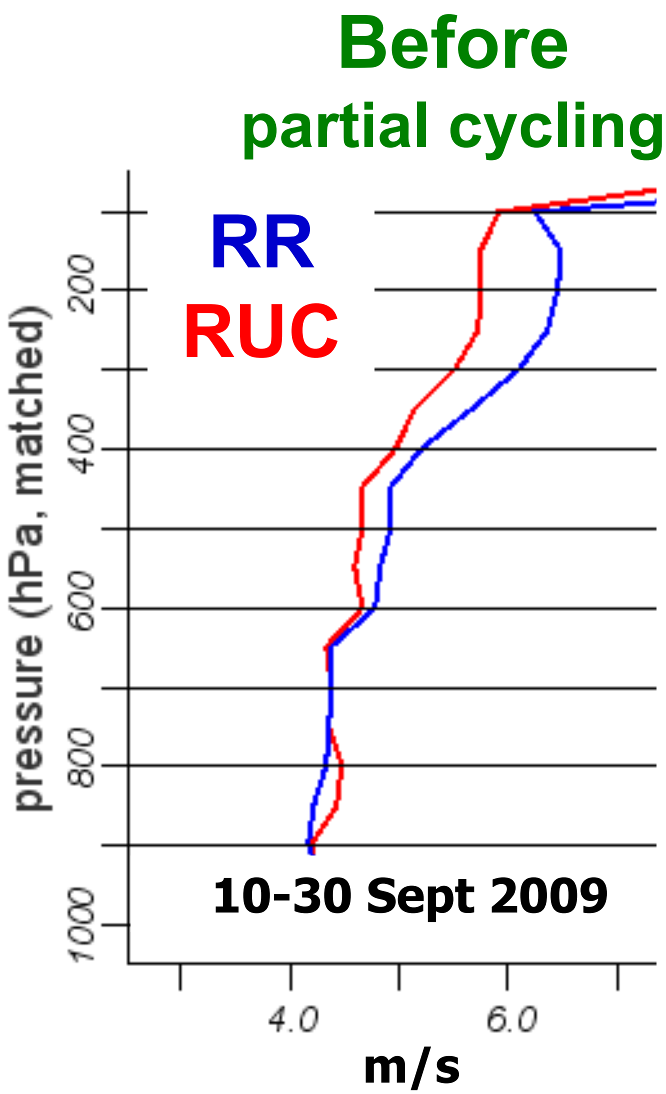
Gradual error growth, especially at upper-levels from large-scale inaccuracies

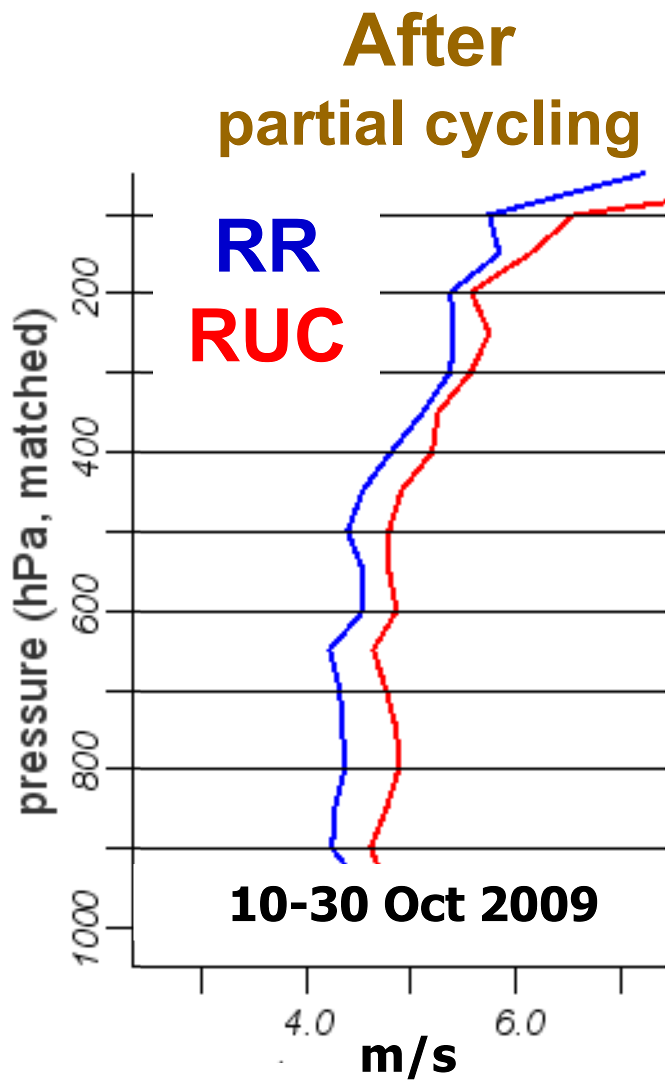
After partial cycling

Much improved results, better skill than RUC

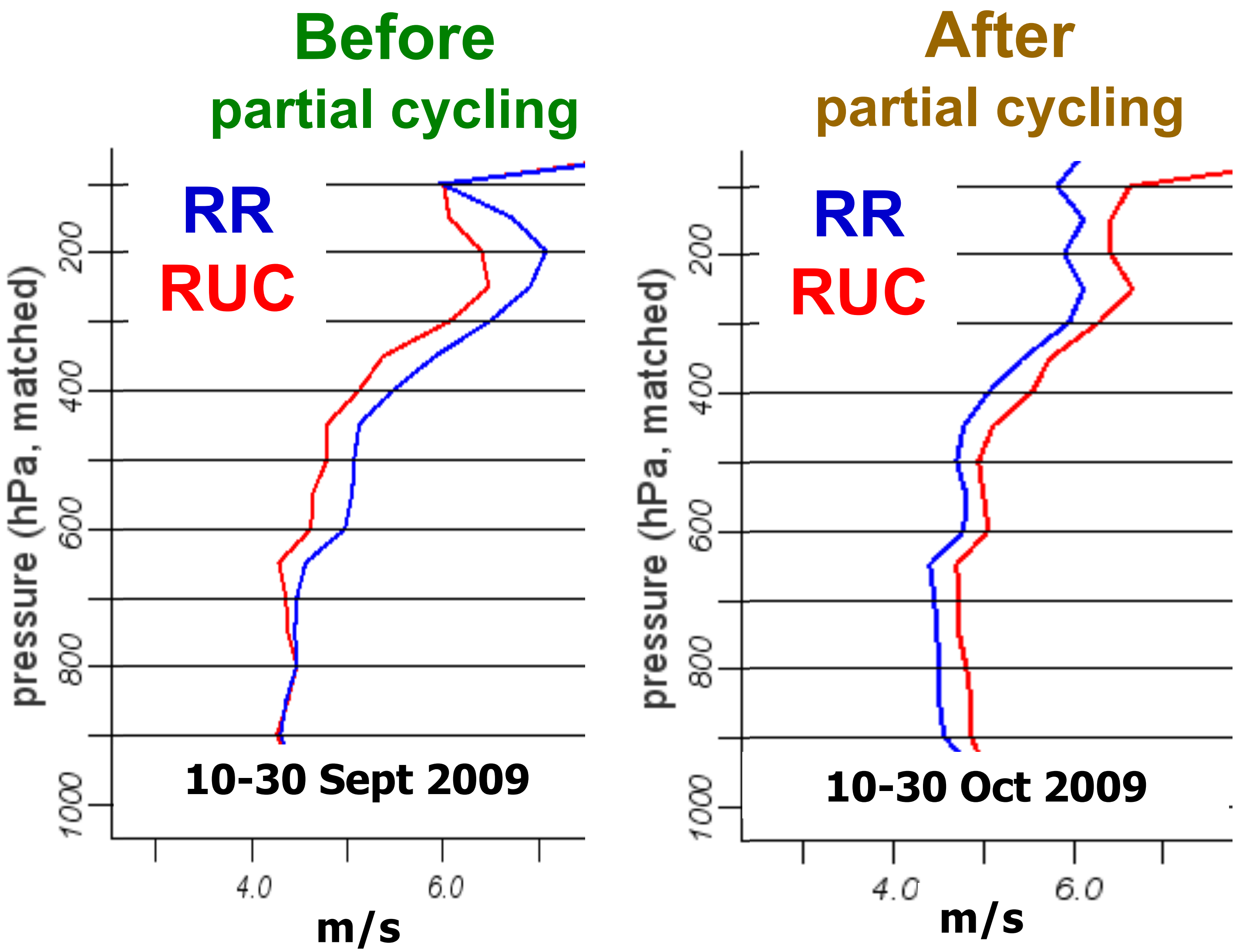


Rapid Refresh upper-air verification
3-h fcst vector wind RMS error

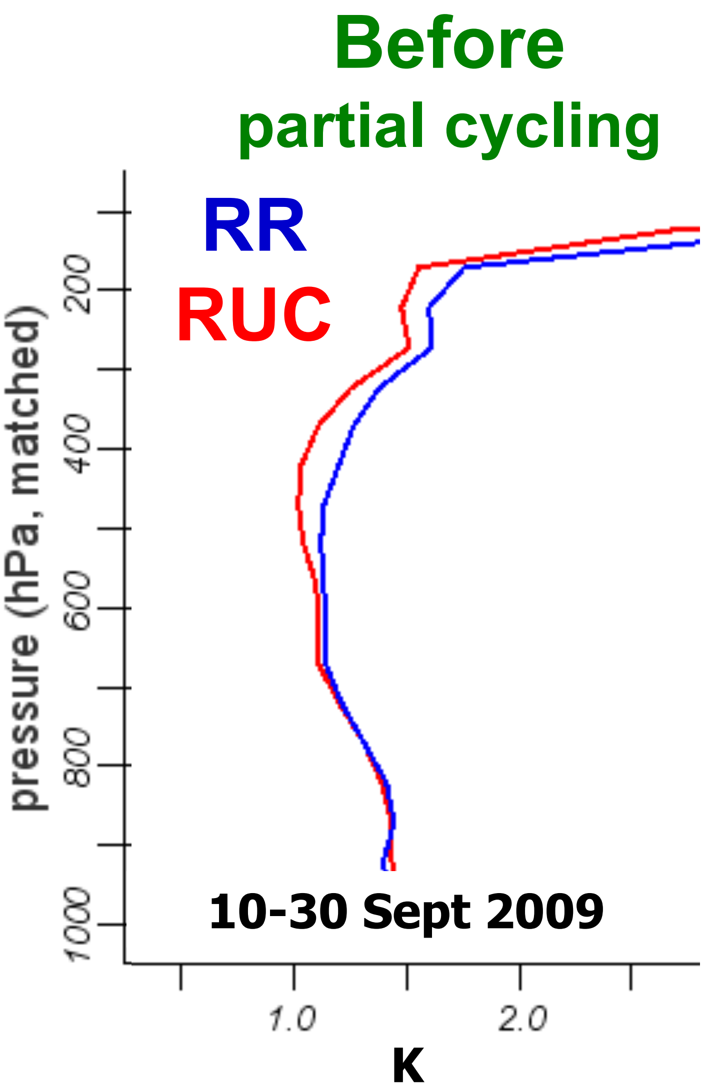


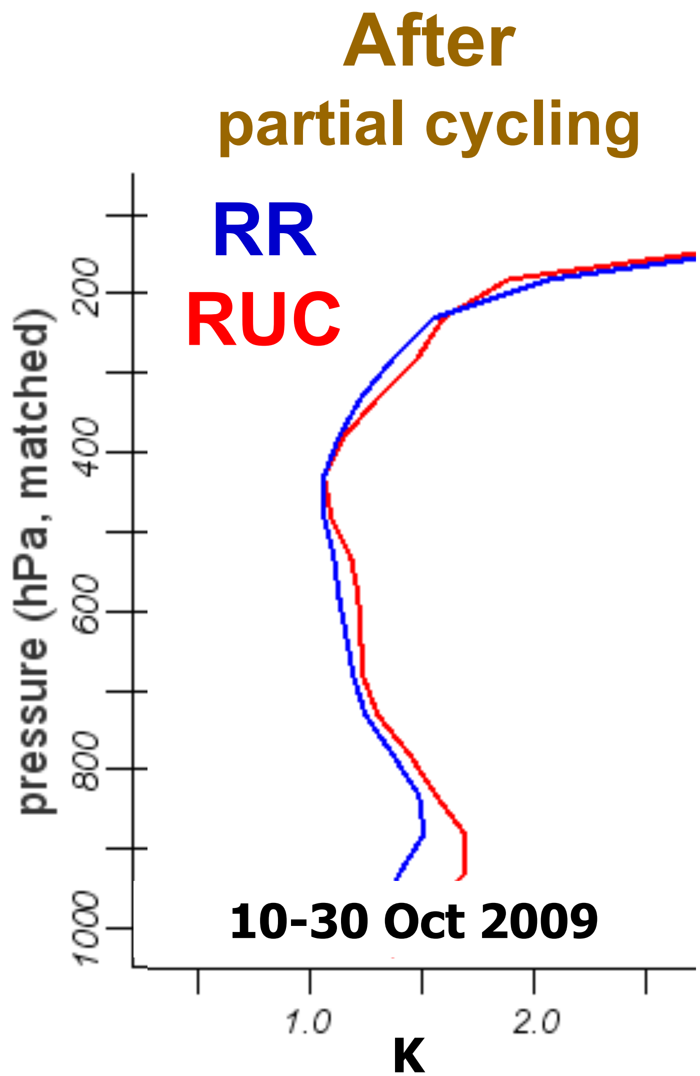


Rapid Refresh upper-air verification
12-h fcst vector wind RMS error

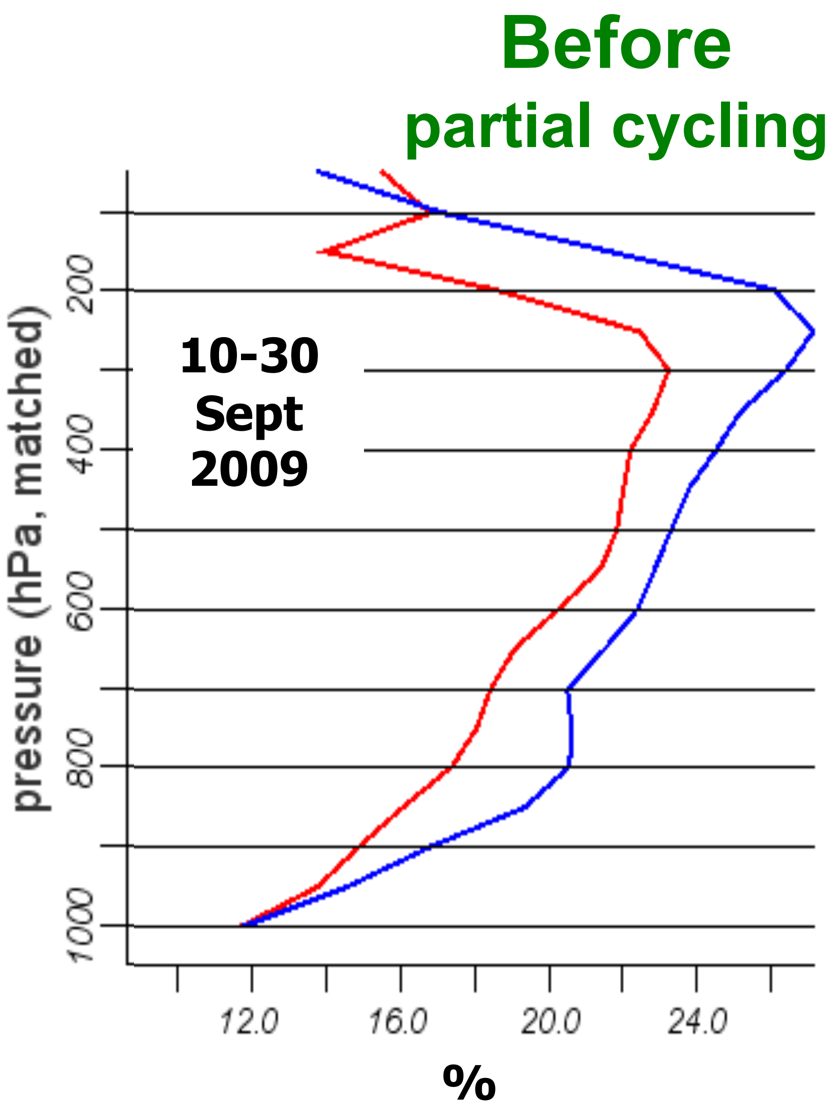


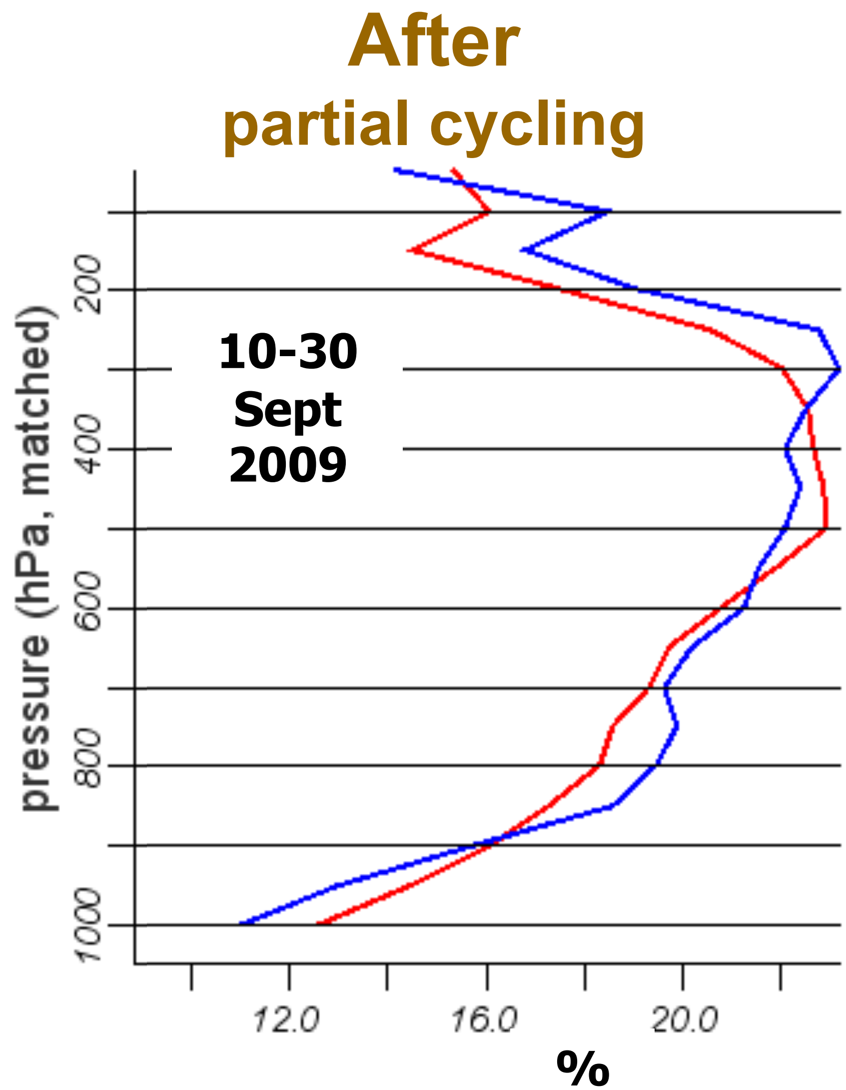
Rapid Refresh upper-air verification
3-h fcst Temperature RMS error





Rapid Refresh upper-air verification
3-h fcst Relative humidity RMS error





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  RR skill similar RUC

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- Verify against Stage 4

  RR similar skill, somewhat higher bias

RR vs. RUC surface verification

RR RMS errors nearly equal to RUC
RR bias errors equal to or better than RUC

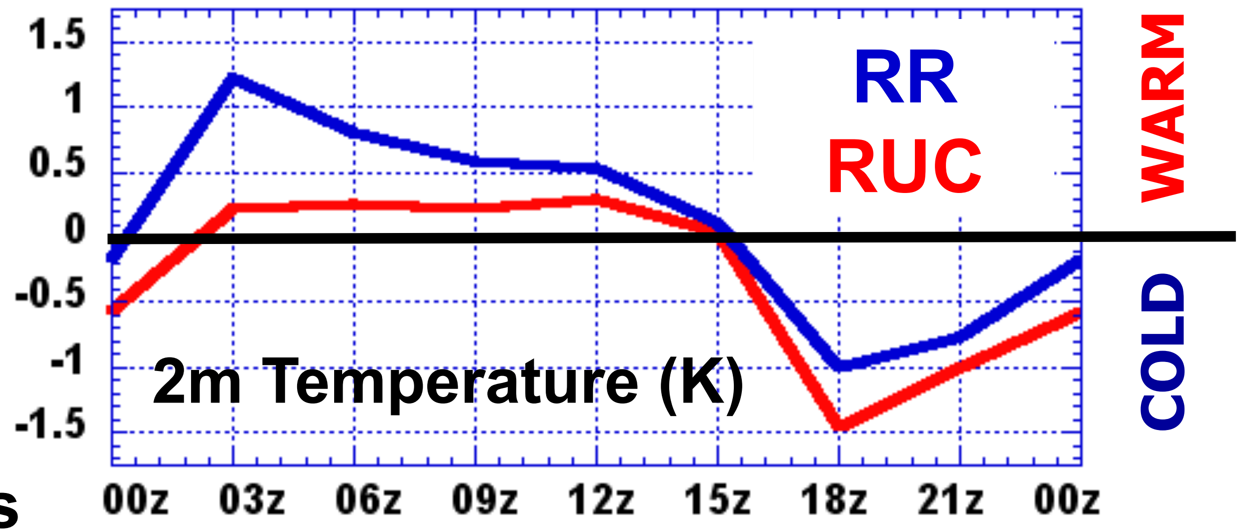
3h fcst errors vs. METARs	rms RUC	rms RR	bias RUC	bias RR
2m Temp. (C)	1.7	2.0	-0.2	+0.2
2m Dew Pt. (C)	1.8	1.8	+0.9	+0.9
10m wind Speed (m/s)	1.9	2.1	+0.6	-0.1
10m vector Wind (m/s)	3.9	4.1		

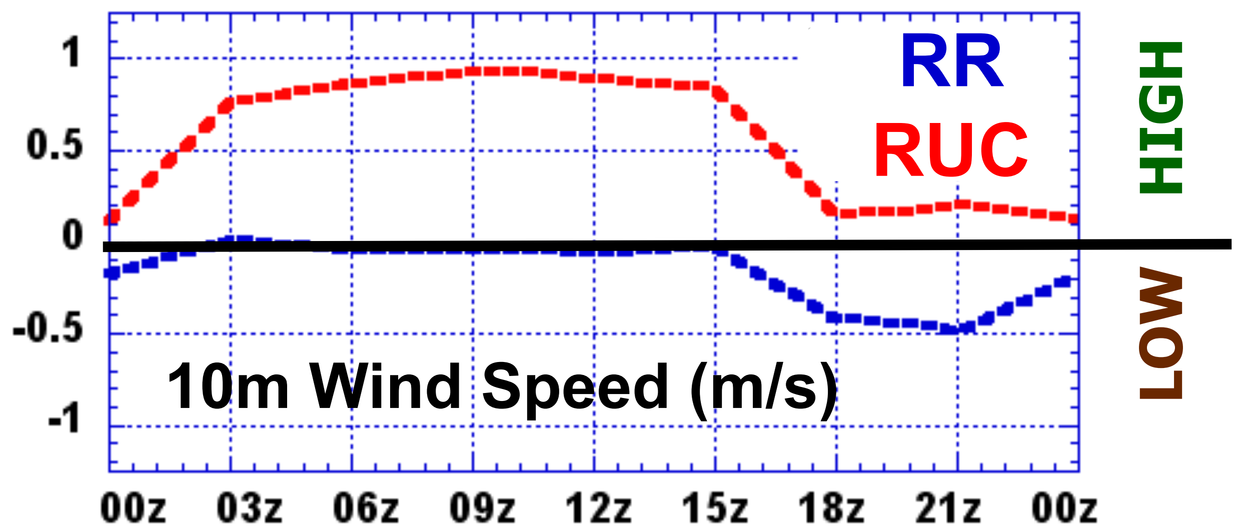
RR vs. RUC surface verification
Diurnal bias variation for 3-h fcst

Diurnal temperature cycle too small in RR & RUC

Daytime too cool, not as bad in RR, consistent wind bias

Nighttime too warm, especially in RR, no bias in RR winds





2-week comparison
14-30 Oct 2009
Eastern US only

Verification (RR vs. RUC)

Upper-air

- Verify against rawinsonde
- Use native level data at 10 mb intervals

  Big pickup from partial cycling

Surface

- Verify against METAR obs for T, Td, wind, ceiling, visibility
- **Surface skill dependent on:**

  data assimilation

  model physics (BL, radiation)

  model post-processing

  RR skill similar RUC

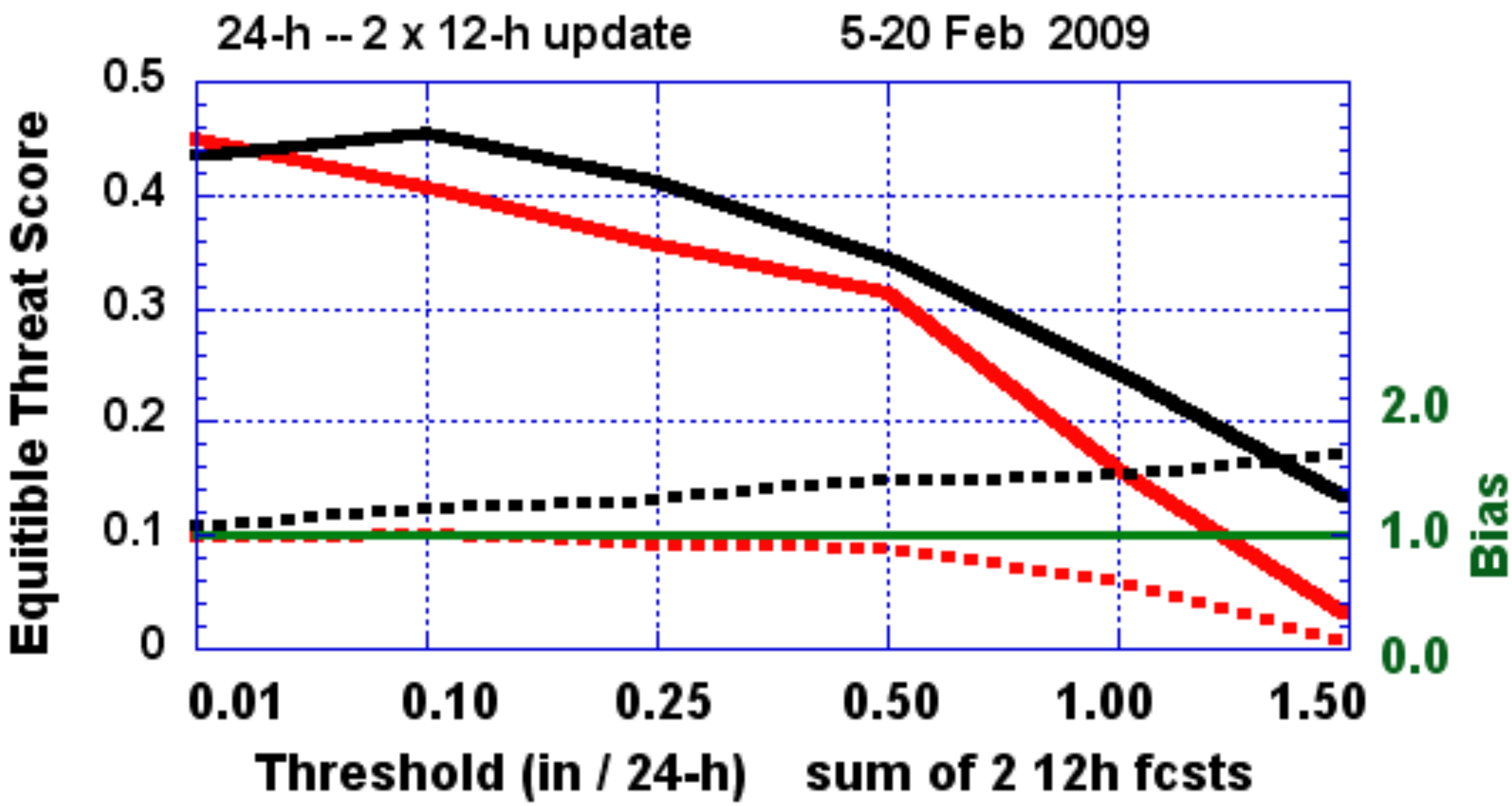
Precipitation verification

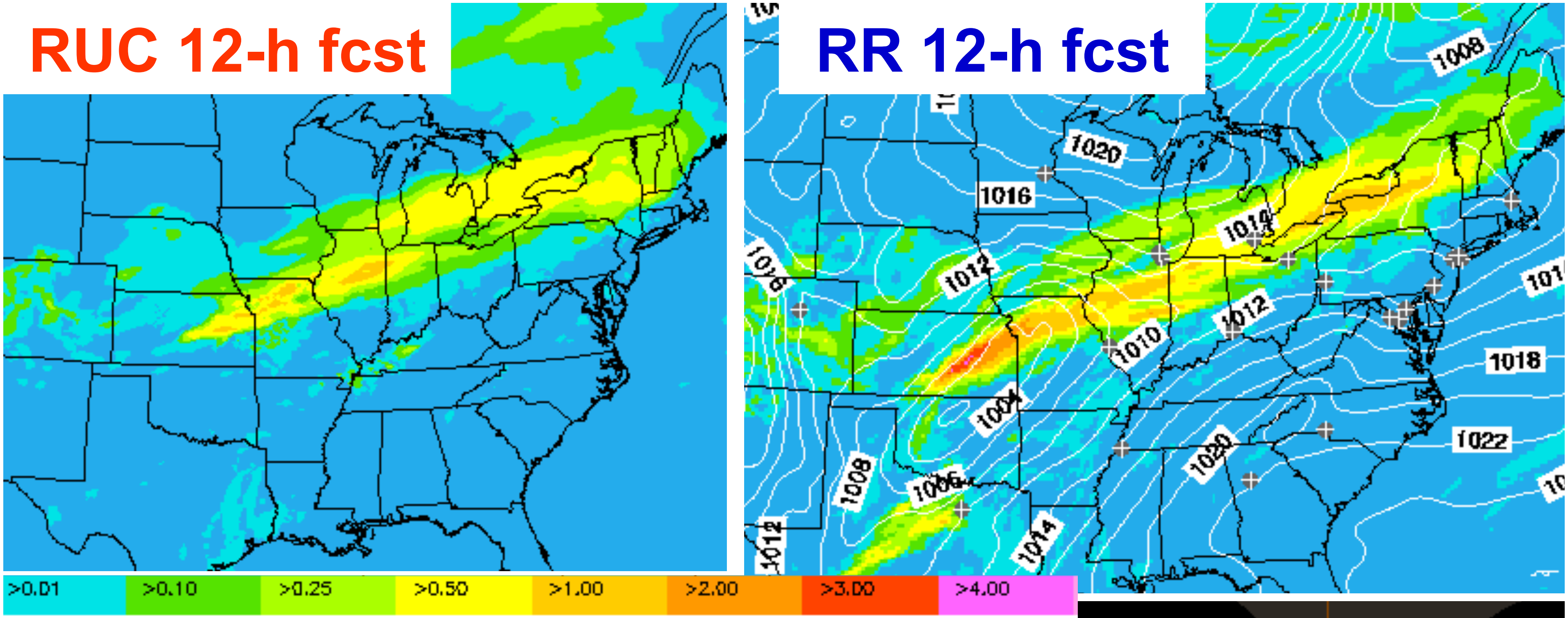
- Verify against Stage 4

  RR similar skill, somewhat higher bias

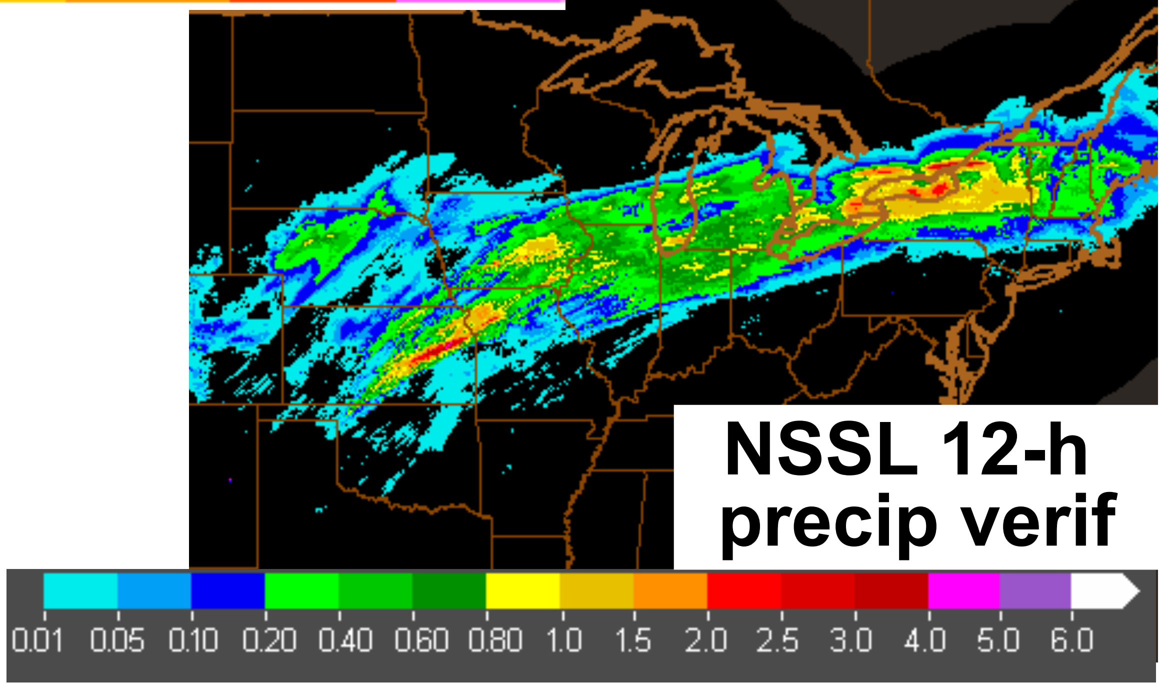
Comparison of Rapid Refresh and RUC precipitation skill scores

- RR has improved ETS for nearly all threshold
- RR bias higher, especially for higher thresholds





12-h accum.
precipitation
06z Mar 8, 2009



Rapid Refresh Status and Plans

- **Current Status → early 2010**
  - **Nearly all modifications in place, good verification**
  - **Final changes based on cycled RR testing (R/T, retro)** (boundary layer assimilation, WRFpost changes)
  - **Transfer code to NCEP, Parallel cycle** (Geoff Manikin)

- **2010 - Q4** **NCEP implementation of Rapid Refresh**

- **2012** **NCEP implementation of Rapid Refresh ensemble**
  - **3 ARW members and 3 NMM members**
  - **using ESMF (Earth System Modeling Framework)**

http://rapidrefresh.noaa.gov

Rapid Refresh / RUC Technical Review - OUTLINE

1:30 – 1:45 RUC➔RR transition overview,
NCEP RUC changes – 2008-09- Stan Benjamin

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Steve Weygandt, Ming Hu

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2:30 – 3:05 RR-WRF model development / testing
– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson

3:05 – 3:20 The HRRR and HCPF (HRRR prob forecast)
Curtis Alexander

3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

Some History of the Rapid Refresh

- 2003-2005 - WRF-RUC testing (WRF initialized with RUC initial conditions)
- 2006 - Controlled ARW, NMM core comparison

  - GSD-AMB recommended use of ARW core by slight margin in Aug. 2006
- Late 2007 - First RR cycling with GSI, ARW

  - Digital Filter Initialization
- 2008-2009 - Extensive testing; Grids → NCAR, AK

  - Two RR 1-hour cycles + retrospective capability

  - RUC cloud analysis and radar initialization

Strong, long-term collaboration with NCAR WRF-ARW developers

GSD Contributions to WRF Code Repository

- RUC-LSM plus periodic updates
- Grell-Devenyi convective scheme (two flavors)
- MYNN (Mellor-Yamada Nakanishi Niino) PBL scheme
- Digital Filter Initialization, including forward diabatic option (with Hans Huang, *et al*, NCAR)

- Changes to metgrid (WPS) to accept RUC native-grid data, including hydrometeors, as input
- Modifications to properly initialize soil when source model and WRF use different Land-Surface Model (LSM)
- Mods to render it possible to run either NMM or ARW with Ferrier or Thompson microphysics, BMJ or GD convection

Key additional contribution: Primary coordination and construction of WRF-Chem code elements

RR version of WRF model

ARW core (currently WRF v3.1 release, April 2009)

Components in red match RUC

Grell-Devenyi convection

MYJ (NCEP/NAM) surface layer,

turbulent vertical mixing above surface layer

NCAR-Thompson microphysics (latest repos version)

RRTM longwave radiation

Goddard shortwave radiation (includes cloud effects)

RUC Land-Surface Model (with recent enhancement to treat snow cover on sea ice)

Diabatic Digital Filter Initialization (DDFI) radar assim

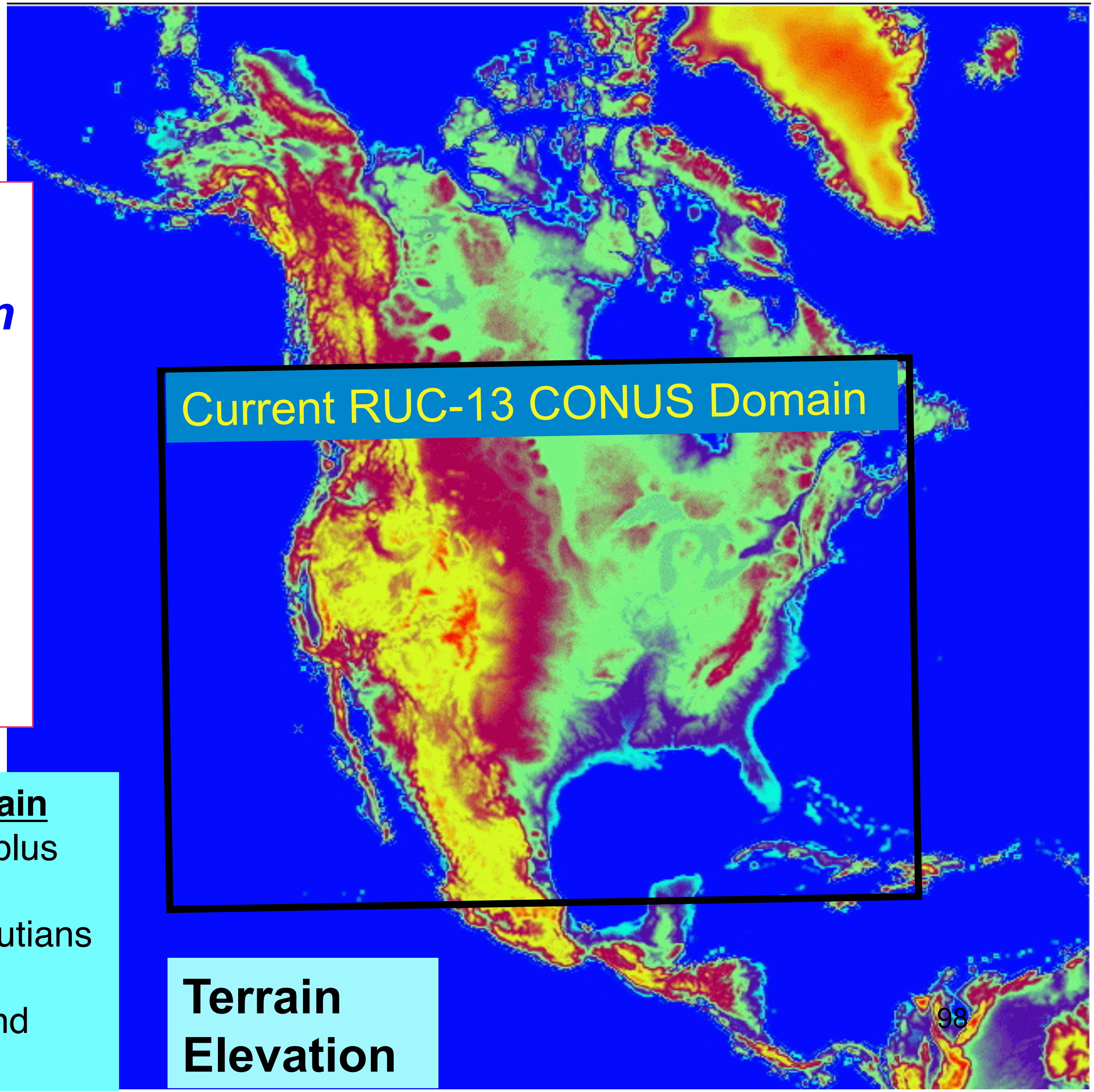
Result: RR physics behavior similar to RUC – good for aviation applications and convective environment

Planned Rapid Refresh ***domain***

-

649x648x50 grid pts

Nominal 13km grid spacing

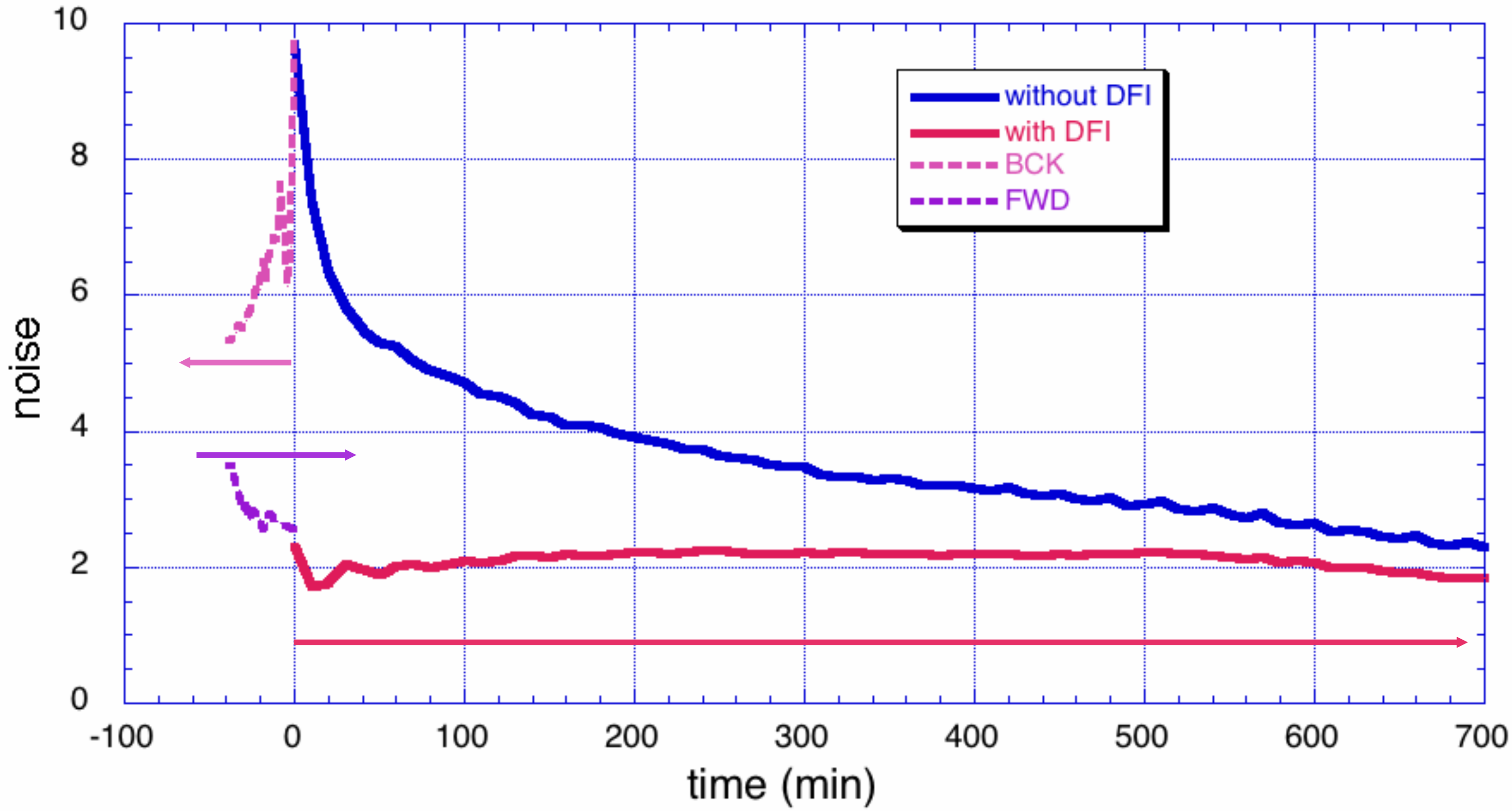


Terrain Elevation

<u>Constraints on domain</u>
- Continental Alaska plus coastal margins
- Dutch Harbor in Aleutians
- Isthmus of Panama
- US Virgin Islands and most of Caribbean

Noise = mean absolute sfc pressure tendency (hPa/h)

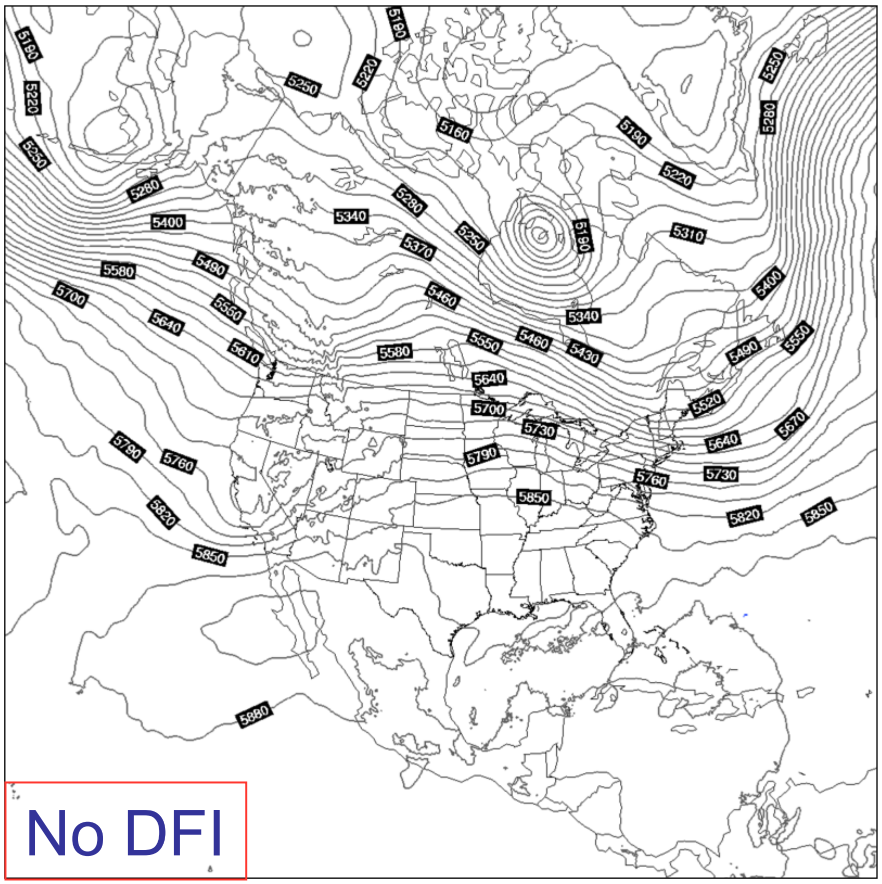
$$\overline{\left|\frac{\partial p_{sfc}}{\partial t}\right|}$$

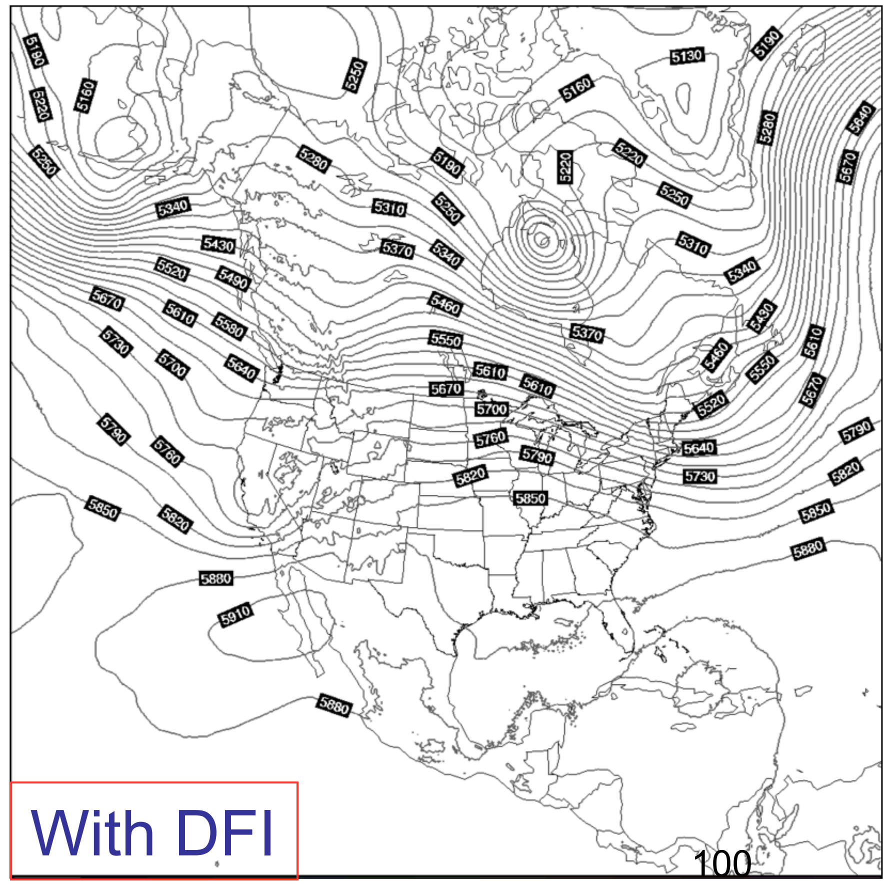


Using WRF-13km Rapid Refresh over N. American domain

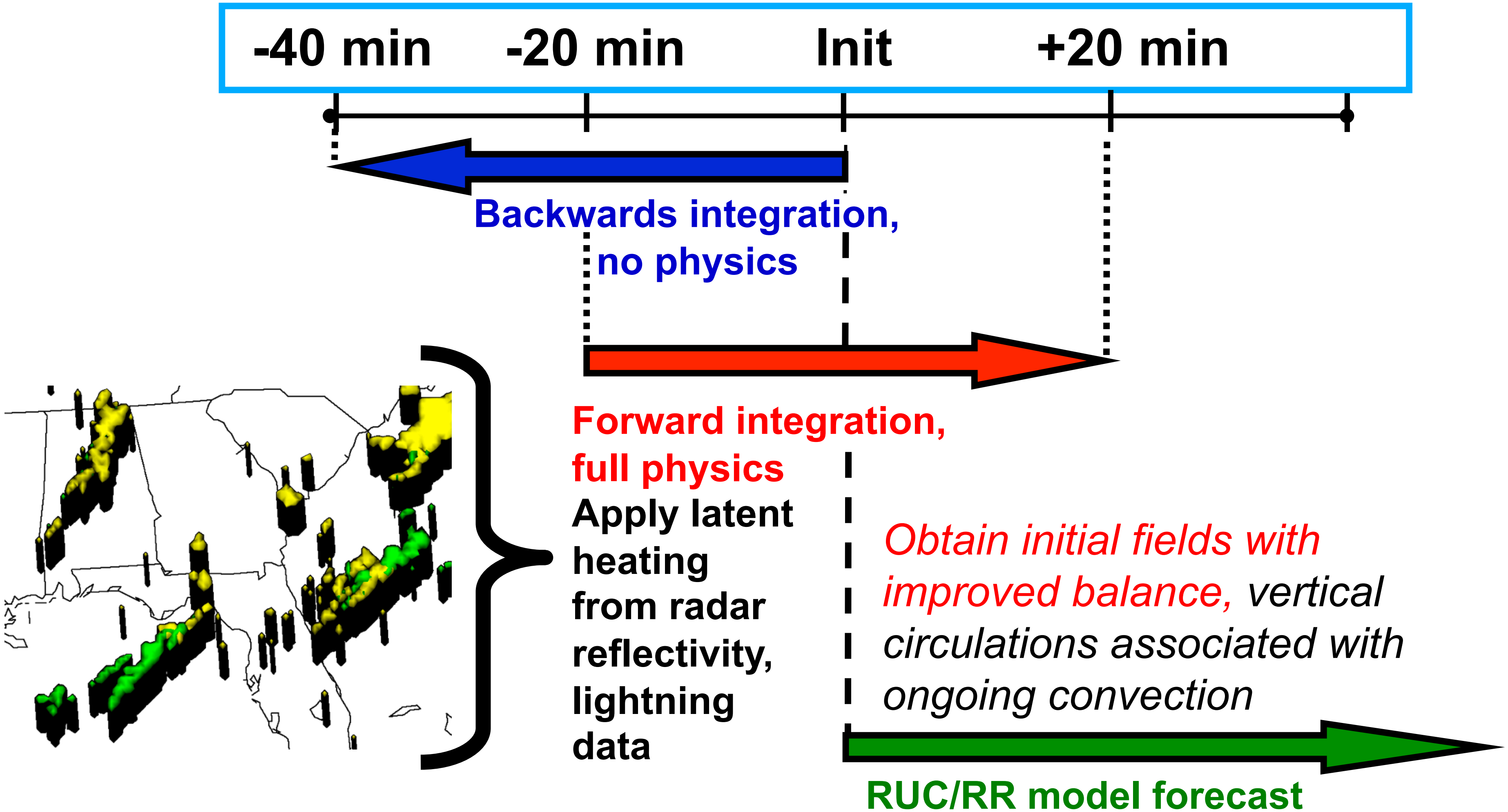
500hPa Height 3-h Fcst for 03Z 30 Oct 07

Away from terrain and convection, height contours are smoother with DFI





Diabatic Digital Filter Initialization (DDFI)



NCAR-Thompson Microphysics

RUC uses Dec 2003 version of scheme

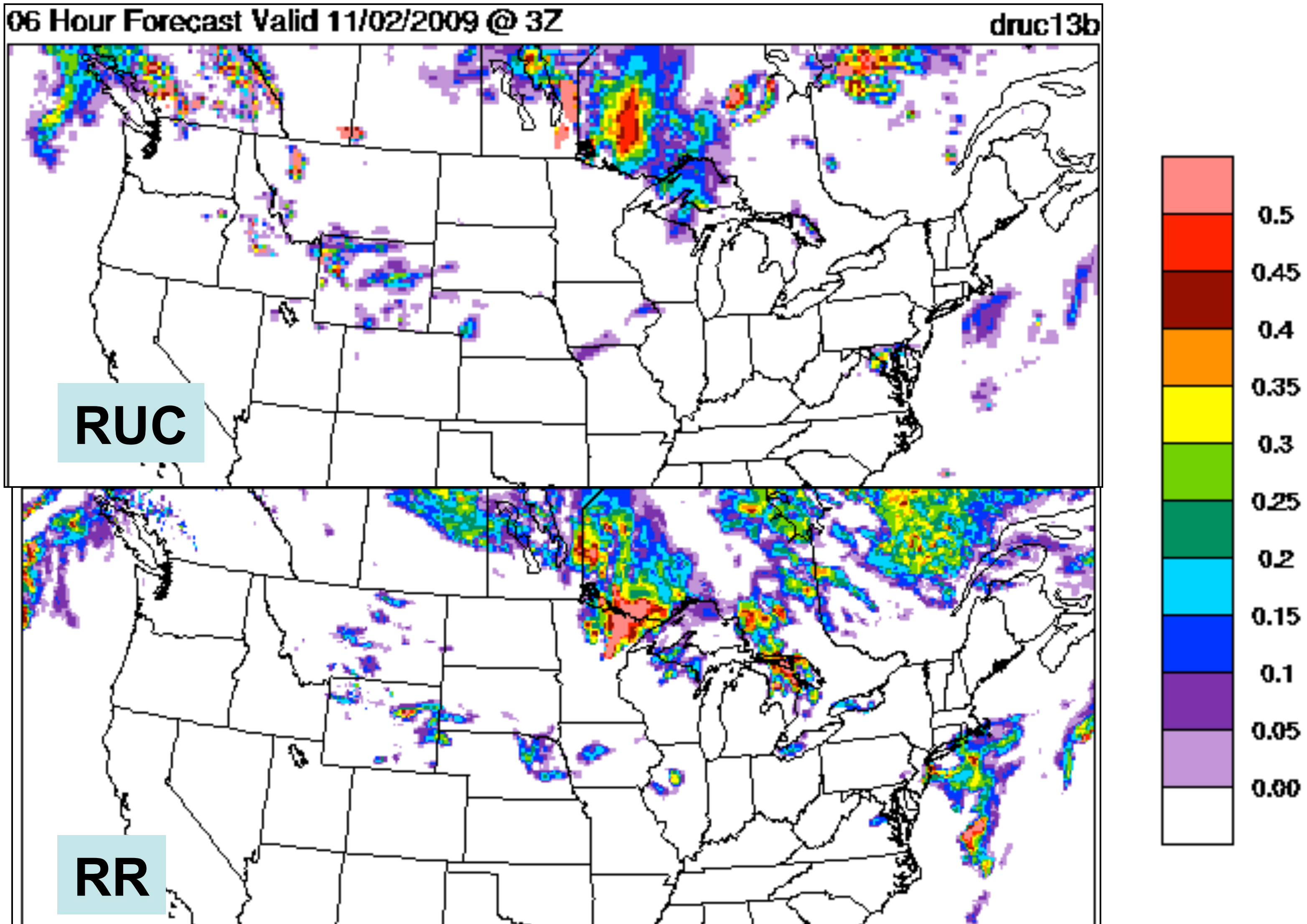
Version in WRF v3.1 (mp_physics = 8) has many changes

- 2-moment (mixing ratio and number concentration) rain
  helps better simulate difference in drop-size distribution between rain resulting from melting snow and that from collision-coalescence of cloud drops
- Greater ice supersaturation allowed (up to water saturation)
- Snow particles assumed to be more 2-d than spherical (affects deposition, collision and fall speed)
- Revised collection of snow and graupel by rain
- Extensive use of lookup tables
- Option for Gamma distribution for all precip hydrometeors

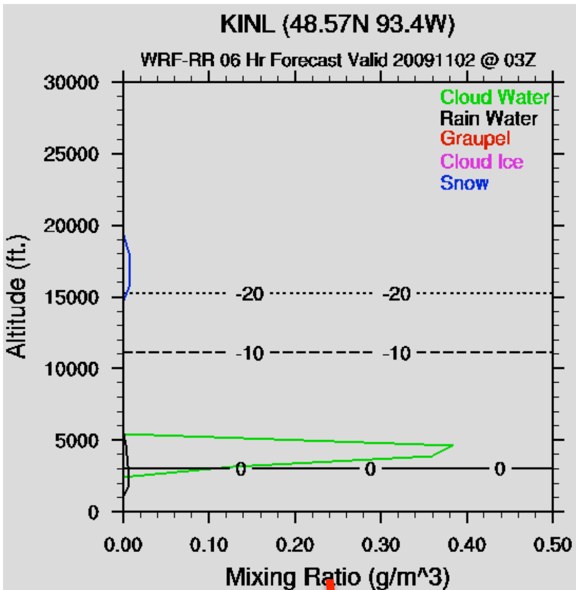
Subjective impressions for RR: Less graupel, more cloud ice and snow than in RUC version

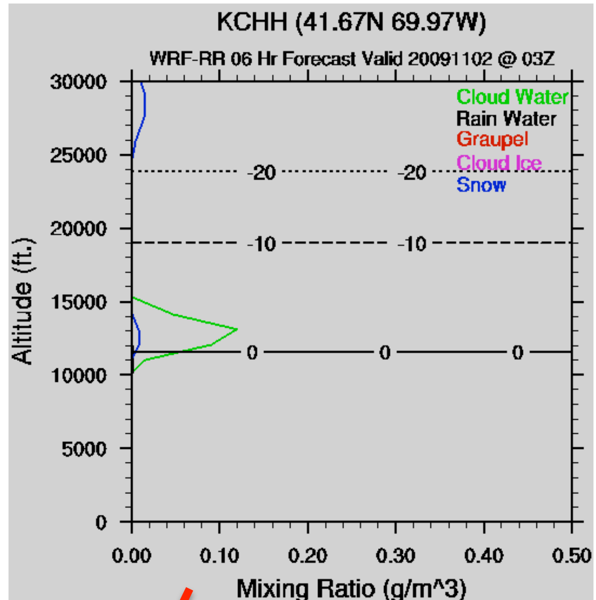
Max supercooled cloud water (g/m^3)

RR and RUC 6-h forecasts valid 03UTC 2 Nov 09

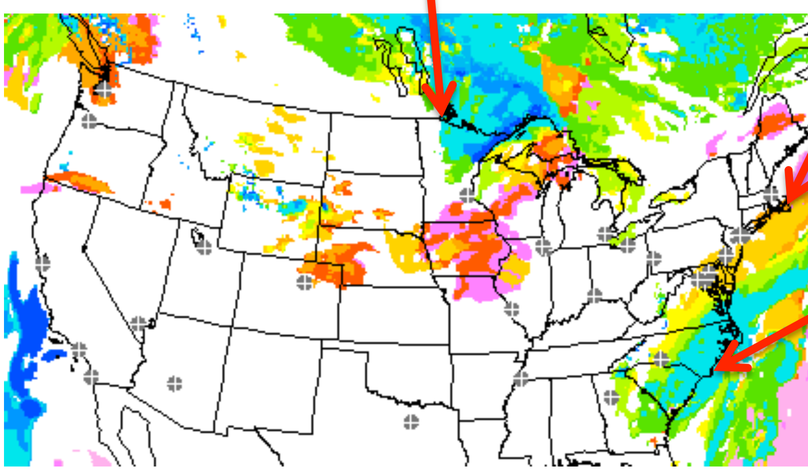


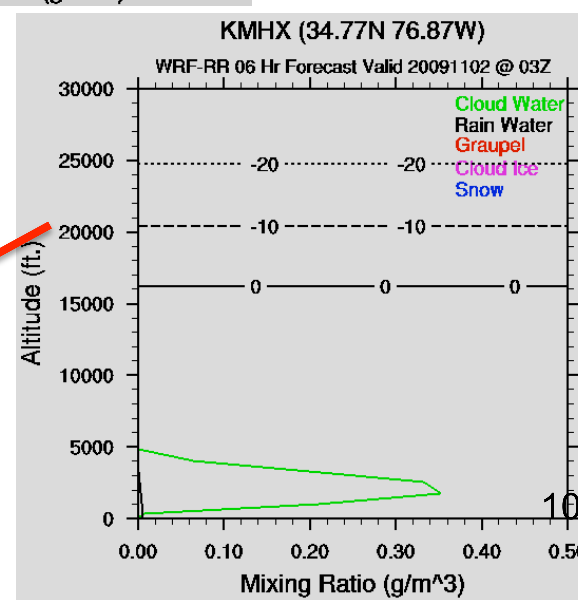
RR hydrometeor soundings from Cory Wolff, NCAR/RAL





6-h forecasts for 03UTC 2 Nov 09





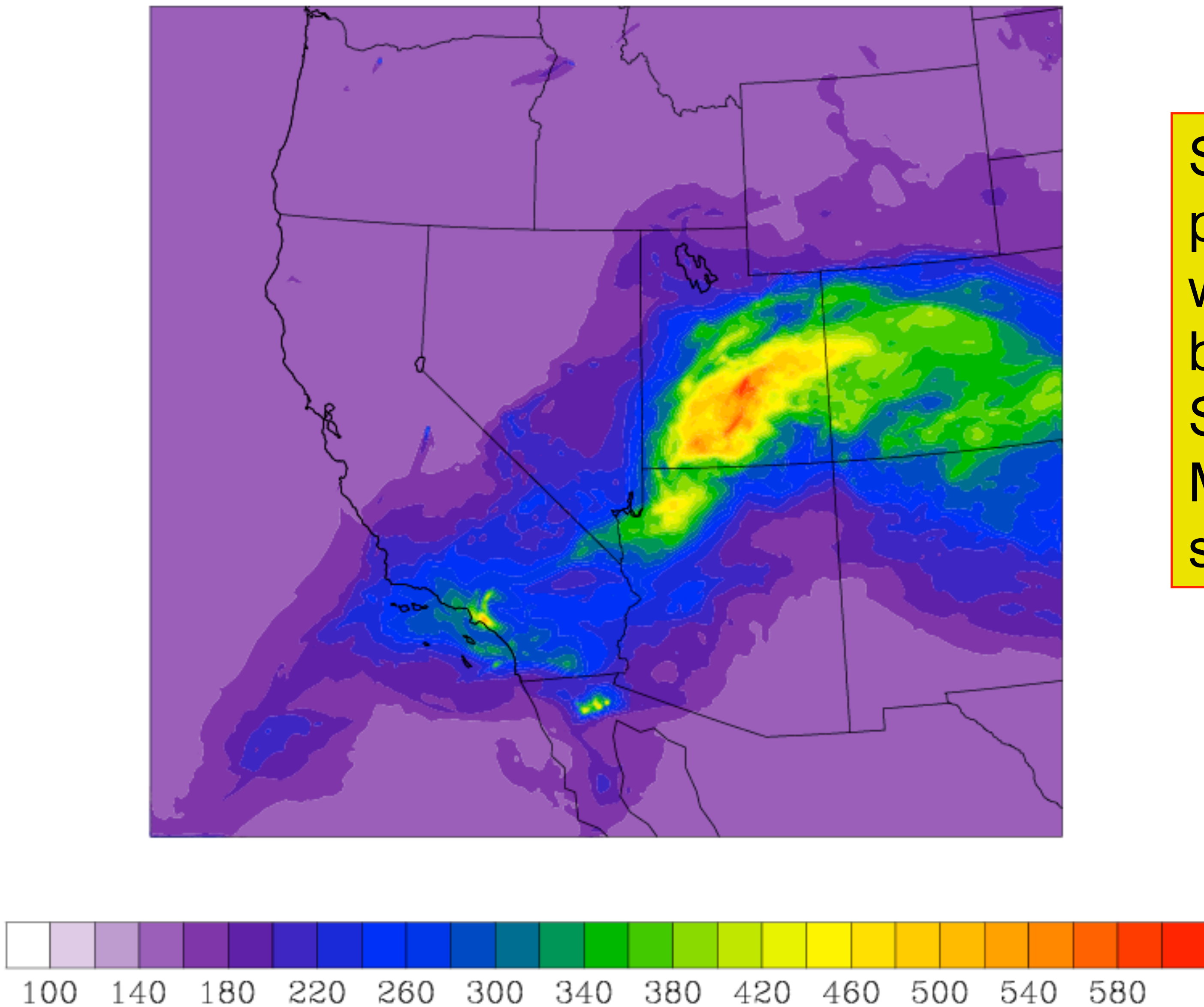
WRF-Chem and RR

Primary WRF-Chem development and coordination occurring in GSD (Georg, Steven, Mariusz)

Next few years: introduce simple version of WRF-Chem into the RR (or even HRRR) as a first step toward **integrated operational weather--air quality forecasting**

- **Aerosol direct effect on radiation** (e.g. solar direct-beam irradiance, surface temp forecasts)
- **Improved warm-rain and ice nucleation in microphysics** (aerosol indirect effects) for better cloud/precip forecasts (impact on ceiling, visibility, icing, surface temp)
- **First step:** RR-Chem put together by Steven and Tanya
  * Once per day to 48h
  * Aerosol cycling only

(HRRR-Chem Vertically Integrated Small Aerosol Concentration (relative units) 1200 UTC 2 Sep 2009



Sources are primarily wildfires, biggest in San Gabriel Mtns, southern CA

Rapid Refresh / RUC Technical Review - OUTLINE

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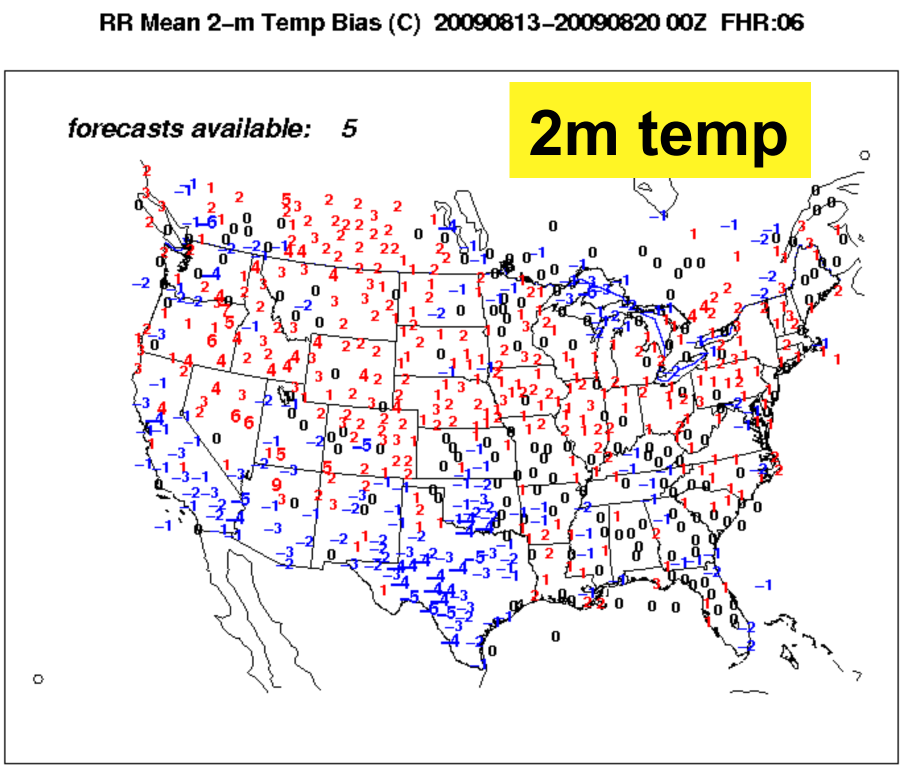
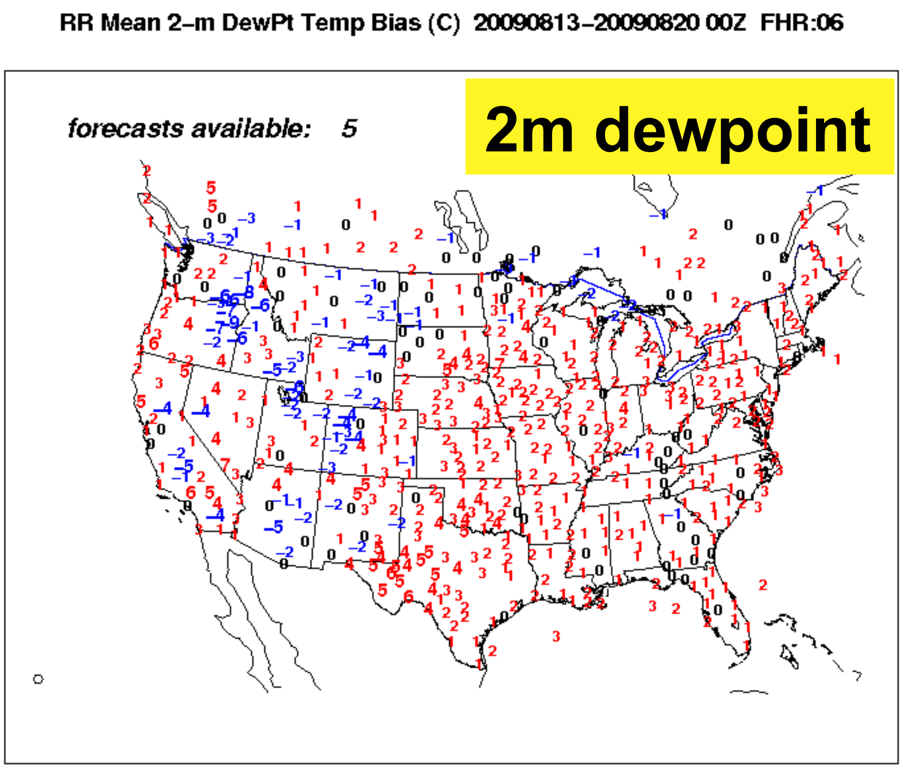
Typical Nighttime Surface Errors within the Rapid Refresh

Weekly composites of fcst hr 06 for all 00Z cycles during 20090813-20.

Error = F-O





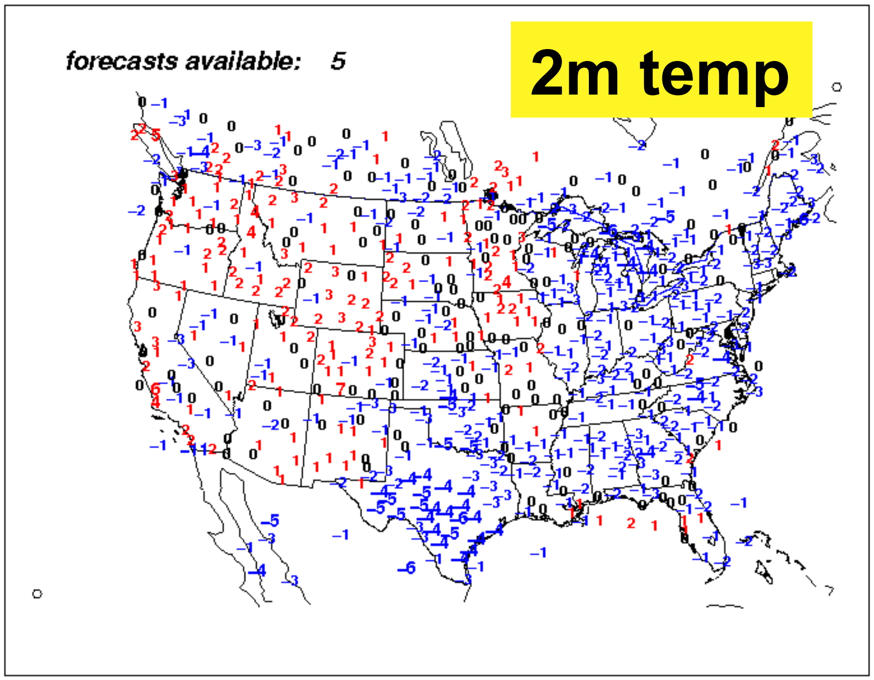
- **RR (MYJ) is generally too warm at night over central plains.**
- **Dewpoint temperatures are typically too high at night.**

Typical Daytime Surface Errors within the Rapid Refresh

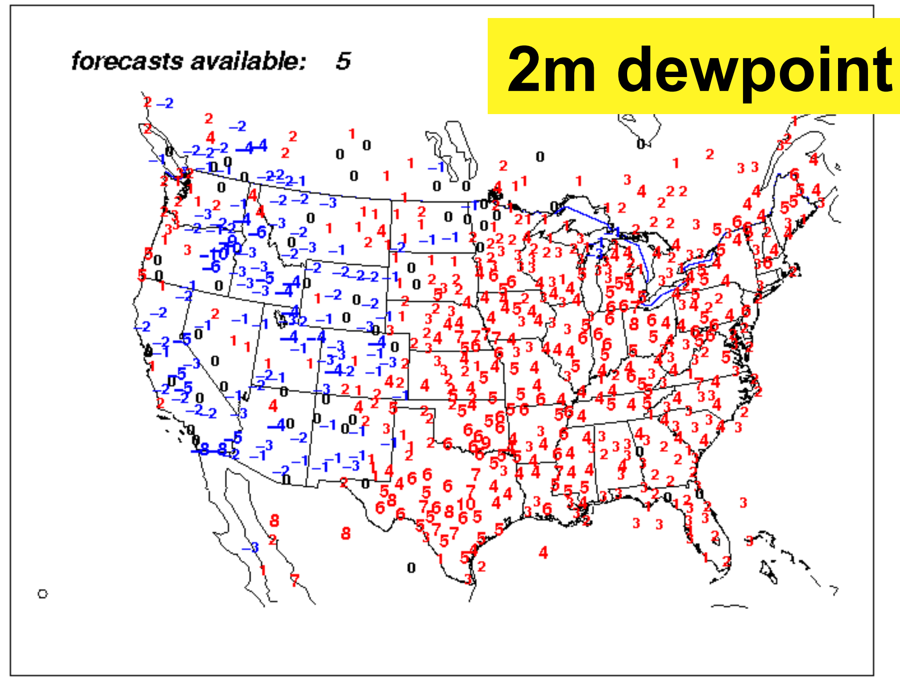
Weekly composites of fcst hr 06 for all 12Z cycles during 20090813-20.

Error = F-O

RR Mean 2–m Temp Bias (C) 20090813–20090820 12Z FHR:06



RR Mean 2–m DewPt Temp Bias (C) 20090813–20090820 12Z FHR:06



- **RR (MYJ) is generally too cool during the day.**
- **Dewpoint temperatures remain too high during the day.**

Investigating the source of surface errors with focus on PBL physics

When transitioning from RUC to RR, a similar TKE-based PBL scheme was chosen, the MYJ:

Model biases commonly reported in the literature (Zhang and Zheng 2004, Li and Pu 2008, among others):

- **Shallow PBL height.**
- **Low surface temperature bias (too cool).**
- **Positive surface moisture bias (too moist).**

Alternative PBL schemes available in WRF-ARW:

YSU

- First-order bulk scheme.
- Includes a countergradient term to parameterize nonlocal mixing.
- Explicit entrainment which is proportional to surface buoyancy fluxes.
- Stronger vertical mixing may alleviate the bias found in the MYJ.

MYNN

- 2.5 and 3.0 level closure.
- The master length scale is a function of 3 independent length scale (turbulent, surface layer, and stable layer).
- Updated stability functions
- Condensation Module.
- Similar physics as MYJ, but tuned to LES simulations for more aggressive vertical mixing.

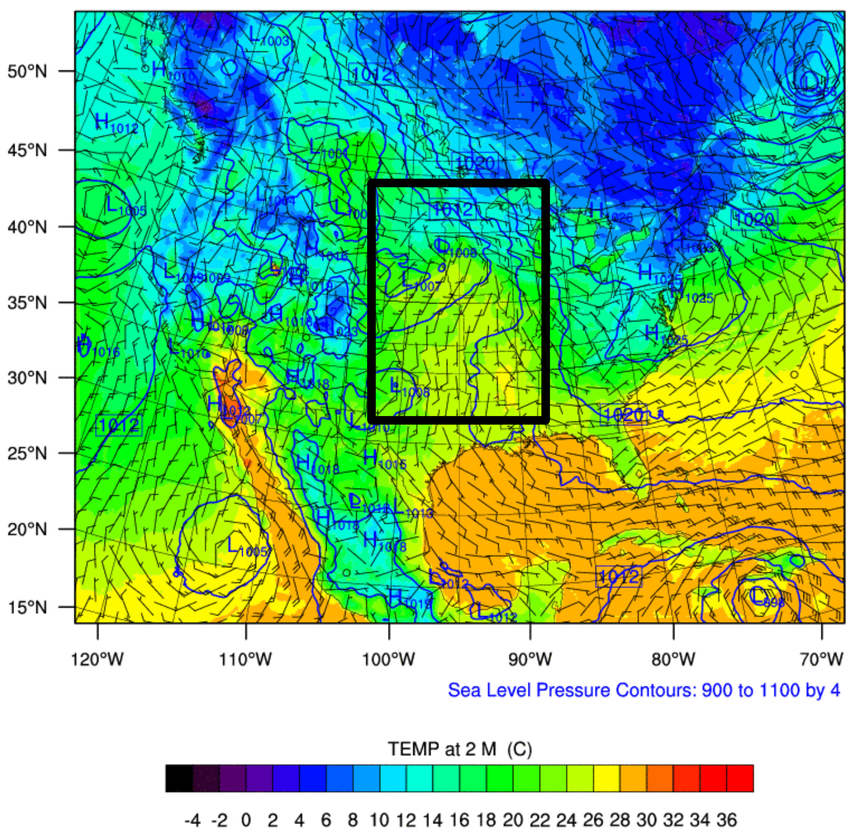
QNSE

- 2.5 level closure; similar to MYJ in neutral-unstable conditions, but in stable conditions, QNSE scheme is activated.
- Turbulent eddies and waves are treated as one entity in the stable regime.
- Similar physics as MYJ, but enhanced treatment of stable nocturnal boundary layer.

PBL Scheme Testing

New candidate PBL schemes need to show skill across RR domain and reduce biases compared with MYJ. Given recent interest in the RR (and HRRR) for wind energy applications, low-level jets and coastal jet cases are good tests for the new PBL schemes.

LLJ case(s) of 20070818-19



WRF-ARW Configuration (v3.1.1):

13.2 and 3.3 km grid spacing

51 vertical levels

RUC LSM

Grell-3 Cumulus Scheme

Thompson Microphysics Scheme

RRTM LW Radiation, Dudhia SW radiation

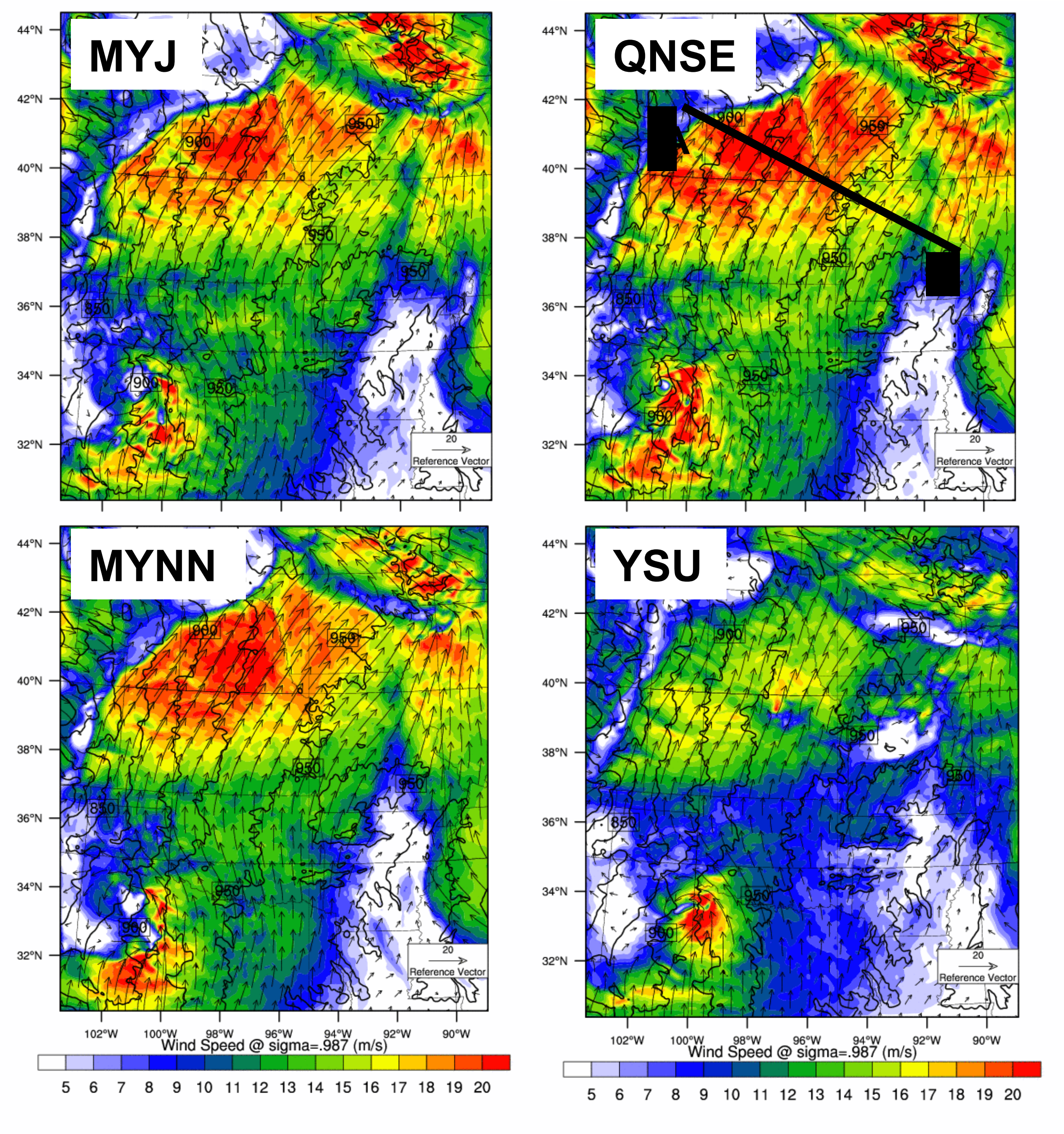
MYJ/MYNN/QNSE/YSU PBL

Initial Conditions:

GFS 6-hourly analyses

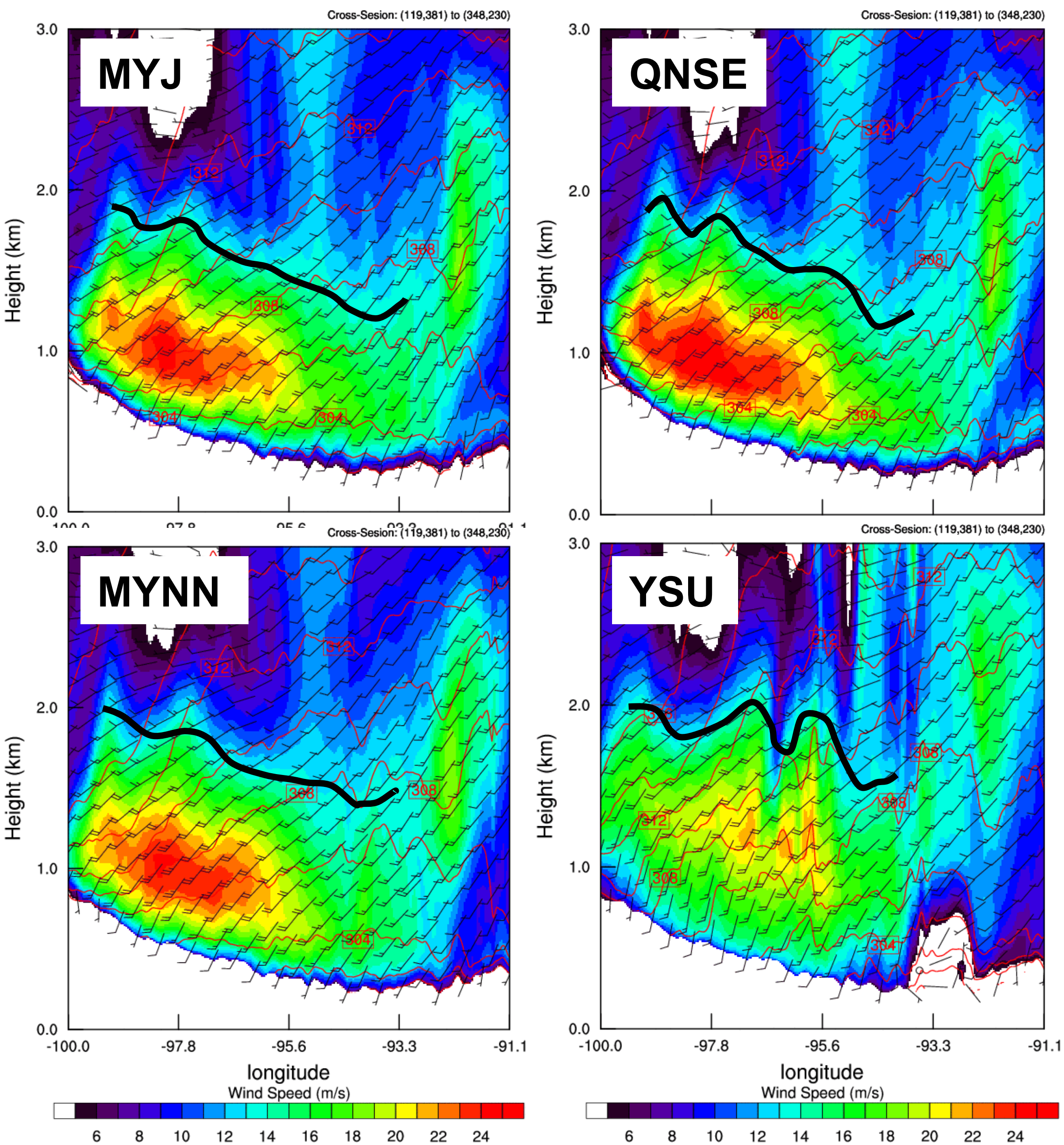
(Actual RR configuration covers all of North America)

100-m wind speed @ 09Z 20070819



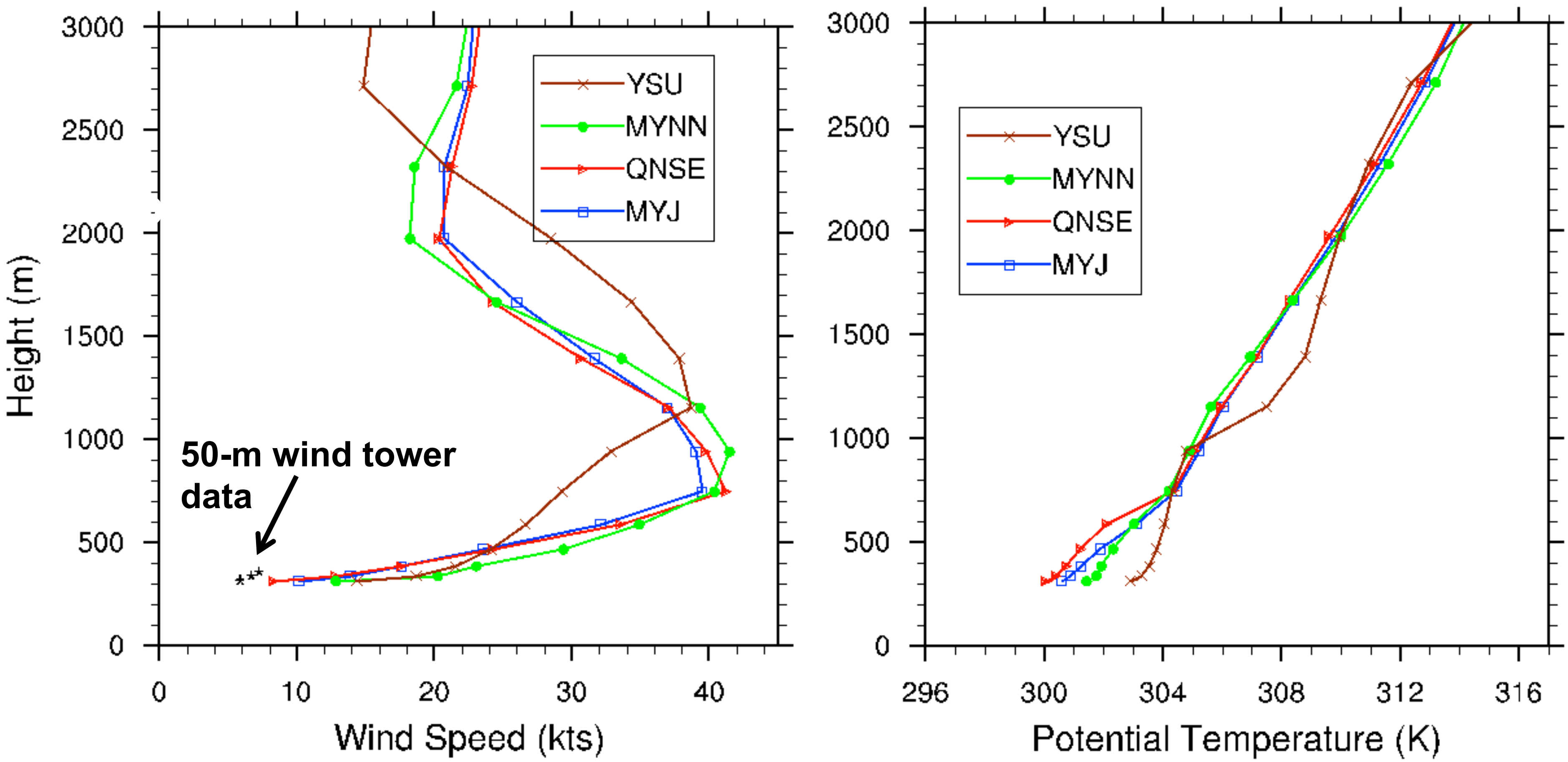
- Spatial extent of high wind speeds is similar in all TKE-based schemes.
- QNSE produces the strongest LLJ, generally 1 m/s stronger than MYJ.
- YSU has the weakest LLJ at the turbine height.

Vertical cross-section @ 09Z



- QNSE produces the strongest and widest LLJ.
- YSU has the weakest and most vertically diffuse LLJ.
- Of the 3 TKE-based schemes, the MYNN has stronger vertical mixing, with the jet top ~100 m higher than MYJ or QNSE.
- Strength of daytime vertical mixing is similar in rank, but has more variation (not shown).

Profile comparison @ 09Z 20070819



Performance across the CONUS region @ 21Z (afternoon) 20070818

Eastern U.S. (east of 100º W)

		TMP	TD	WSP
MYJ	Bias	-0.29	0.79	**0.46**
	MAE	2.73	2.34	**1.52**
MYNN	Bias	**-0.22**	**0.07**	0.66
	MAE	2.75	**2.15**	1.75

Western U.S. (west of 100º W)

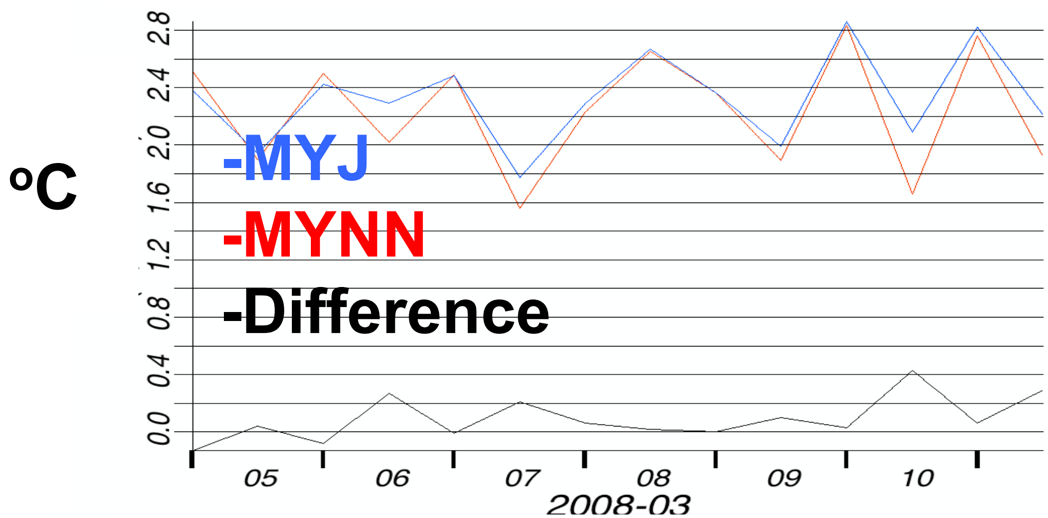
		TMP	TD	WSP
MYJ	Bias	-1.99	0.87	-0.99
	MAE	3.19	2.74	1.96
MYNN	Bias	**-1.25**	**0.04**	**0.37**
	MAE	3.21	**2.46**	1.96

Note: Bold denotes notably better performance

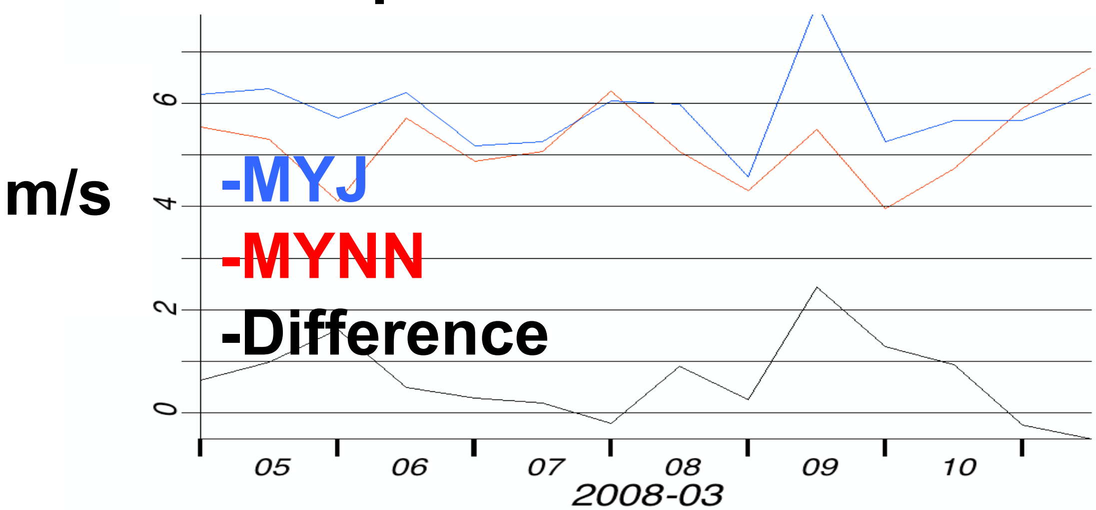
Statistics calculated from ~1500 surface stations.

CONUS 900-1000 mb verification for retro-test period 05-10 March

Temperature RMSE 12HR FCST



Wind Speed RMSE 12HR FCST



- **MYNN outperformed MYJ over the entire CONUS boundary layer.**
- **However, upper level winds were slightly better predicted by MYJ (not shown).**
- **Modifications to MYNN mixing length may remove this problem. New retro test is in queue.**

Summary

- All TKE-based schemes simulate a strong LLJ, while the bulk scheme (YSU) vertically mixes the momentum more strongly.
- The MYNN had slightly stronger vertical mixing compared to MYJ and QNSE, but less than YSU.
- The MYNN generally alleviated the common biases associated with the MYJ, resulting in a slightly warmer and drier surface.
- Other coastal barrier jet case studies (SARJET) show similar relative behavior between the PBL schemes tested (not shown).
- Subject to more testing, the modified MYNN PBL scheme is a candidate for use in a future version of the Rapid Refresh.

Future work

- Examine surface fluxes and near surface mixing of all PBL schemes. Simulations will be compared with Iberdrola wind tower data.
- Assess the potential benefits of assimilating wind tower data into RR system.
- Verify the modified MYNN over retro-period.
- Help debug the TEMF PBL scheme (*Mauritsen et al. 2007 and Angevine 2005*) and add it to the test matrix of simulations.

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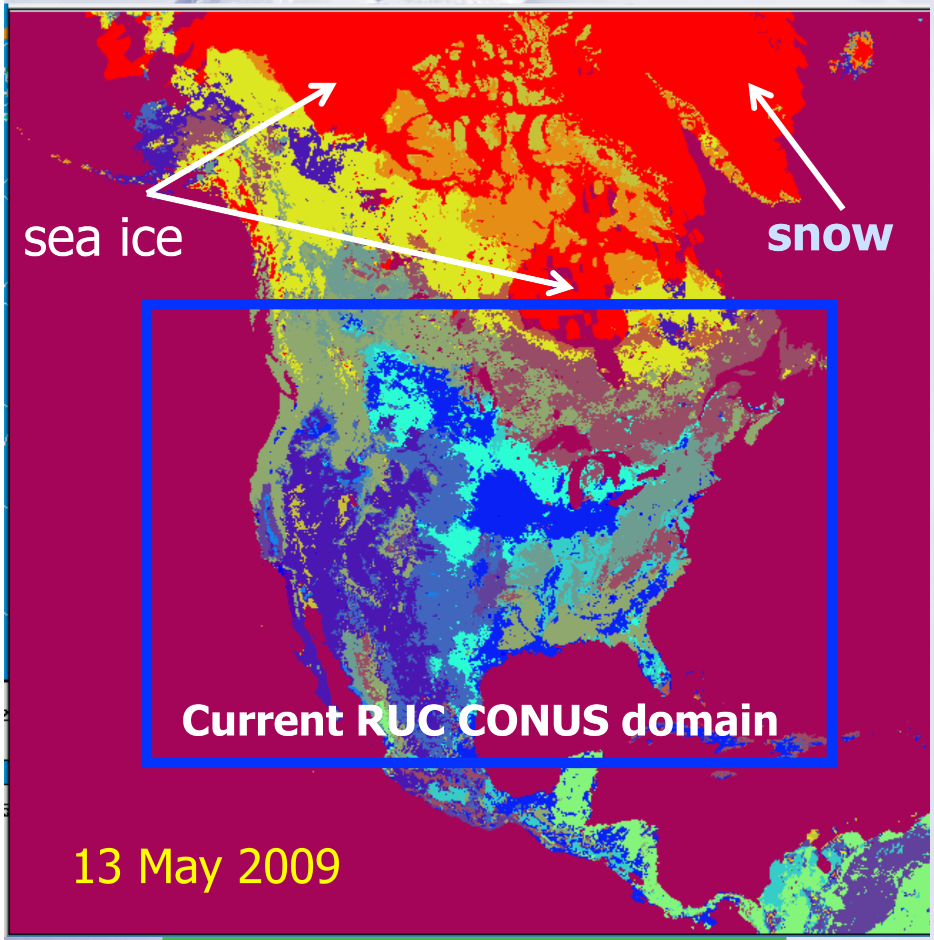
Challenges in parameterization of land surface processes in Rapid Refresh (RR)

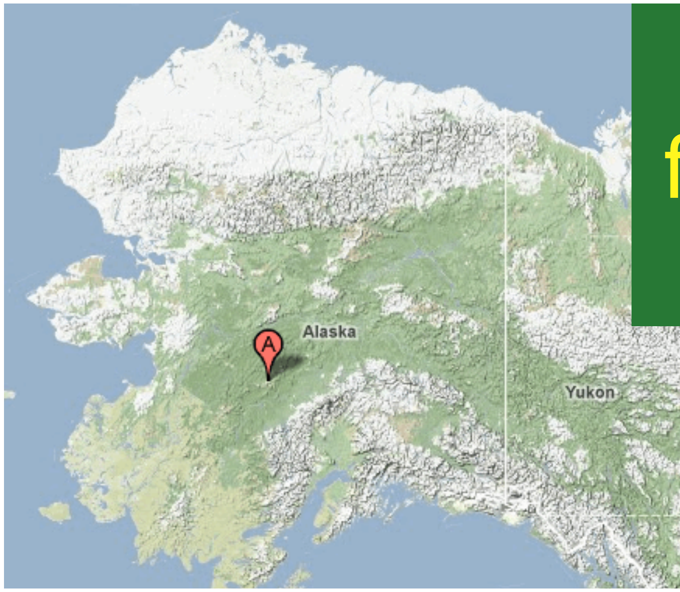


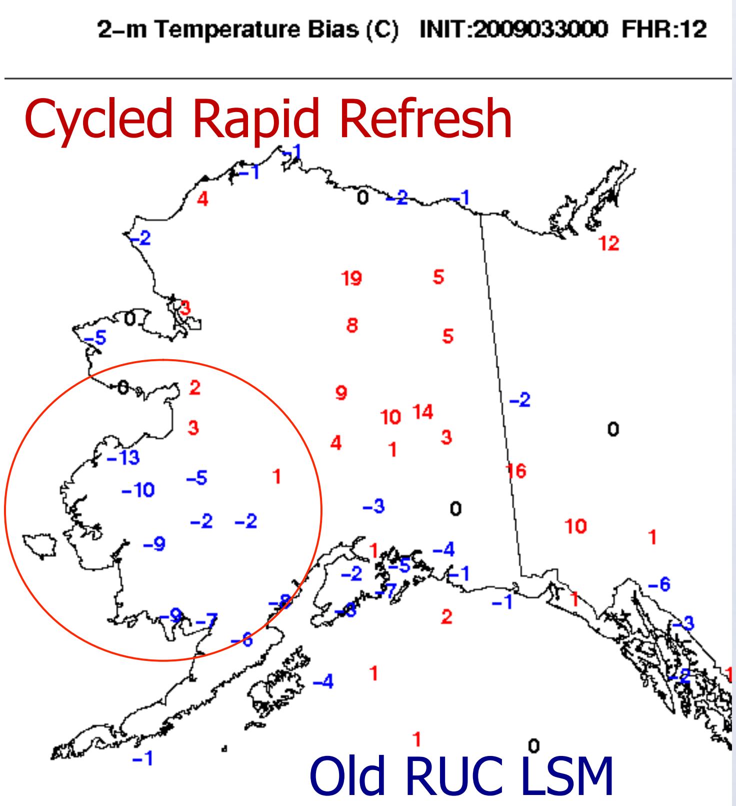
RR land use types

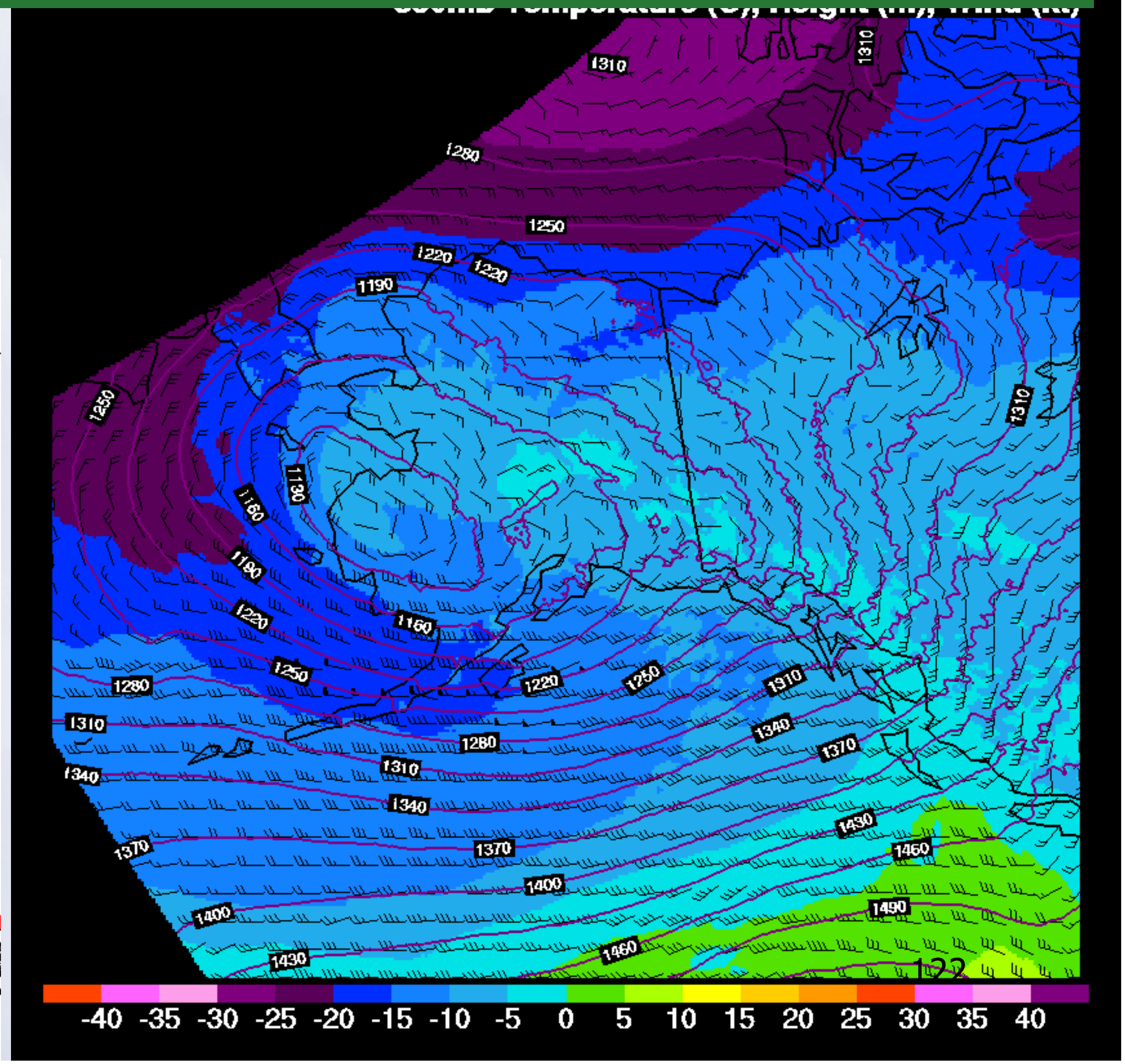
- RUC LSM validation and development for polar application in Canada and Alaska including extended permafrost tundra zones
  - new treatment for sea ice in RUCLSM
  - temperature dependence of snow and ice albedo

- Assimilation of satellite/in-situ data for snow depth, soil moisture, skin temperature
  - use of NESDIS snow/ice data to trim RR snow

2-m temperature verification for Alaska, 12h forecast valid at 12 UTC 30 March 2009



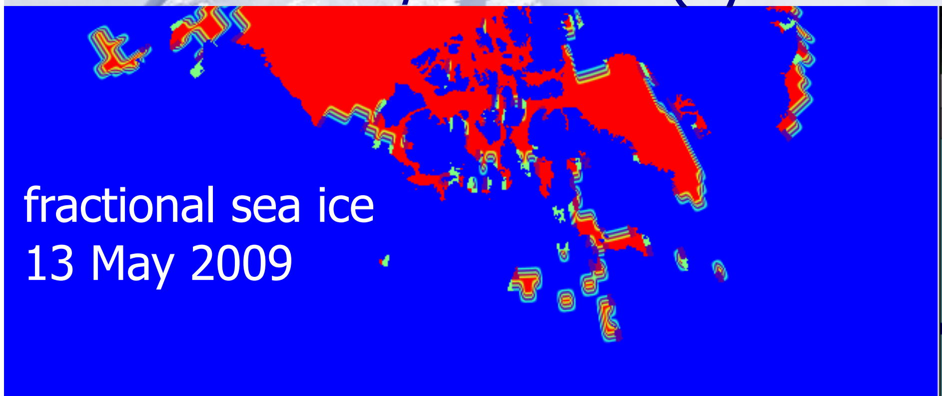


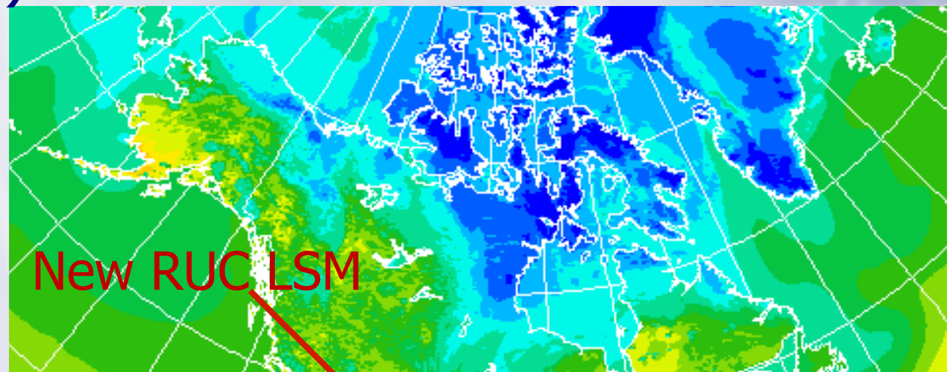


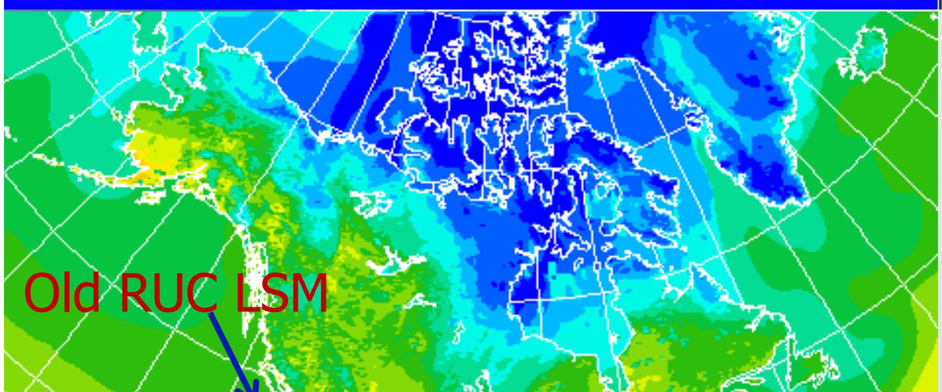
New Treatment for Sea Ice in RUC LSM

Sea Ice is initialized in RR from GFS (cold-start RR) or from NESDIS snow/ice data (cycled RR)

RR 12-h forecasts of Skin Temperature valid at 00 UTC 14 May 2009





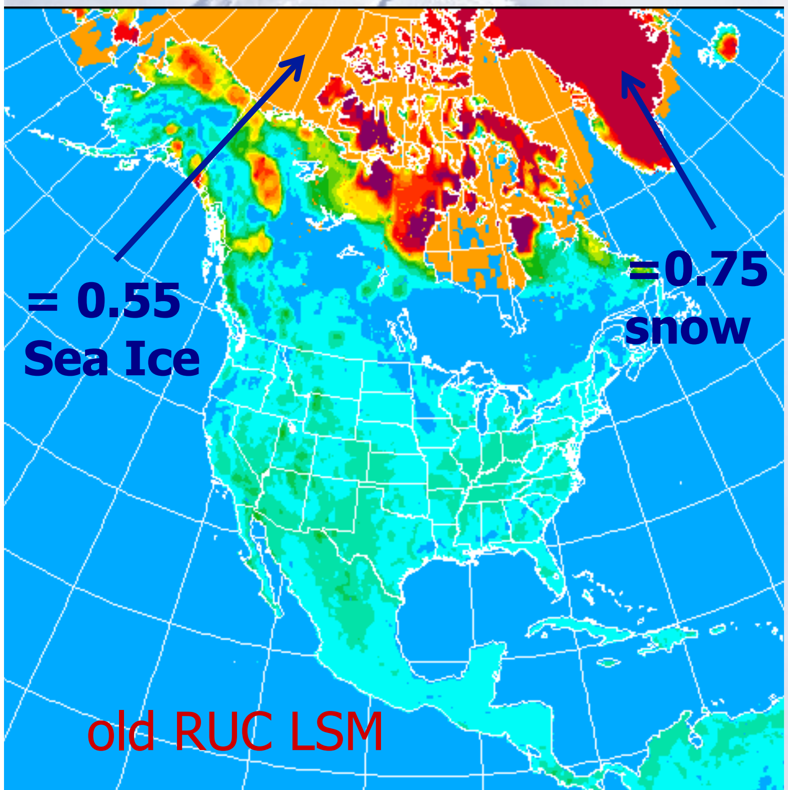


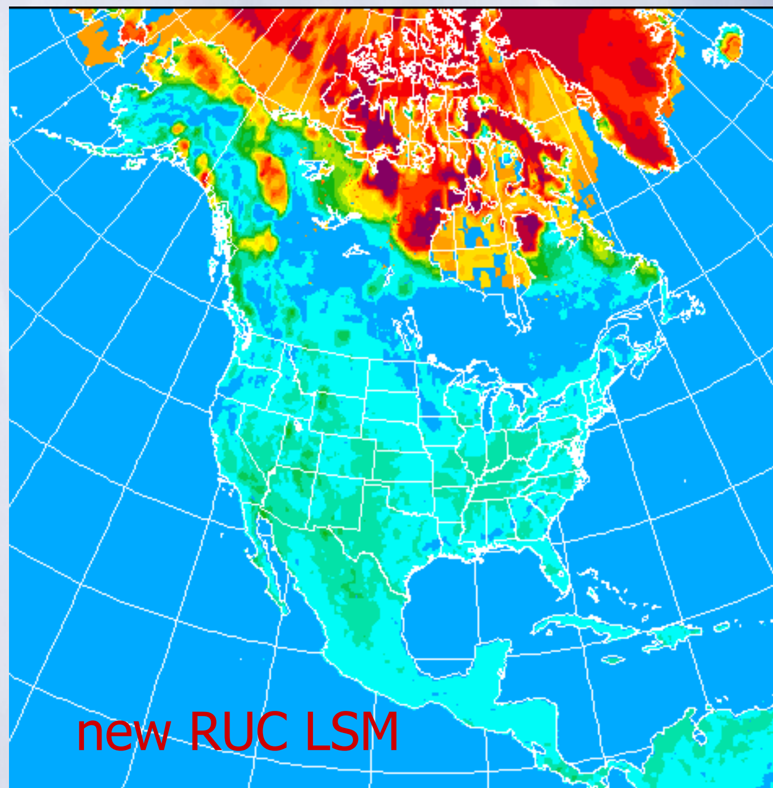
- Skin temperature is prescribed to be equal to temperature at the 1st atmospheric level
- No snow on sea ice

- Solution of surface energy budget and heat diffusion equation in ice
- Snow/Ice Albedo is a function of snow/ice surface temperature
- Snow accumulation on the sea ice surface
- No melting, drifting or building new sea ice
- Option of fractional sea ice

Albedo in Rapid Refresh

- Starts from NESDIS monthly climatological albedo interpolated to a current day
- Updates it for snow and ice using WRF maximum snow albedo data

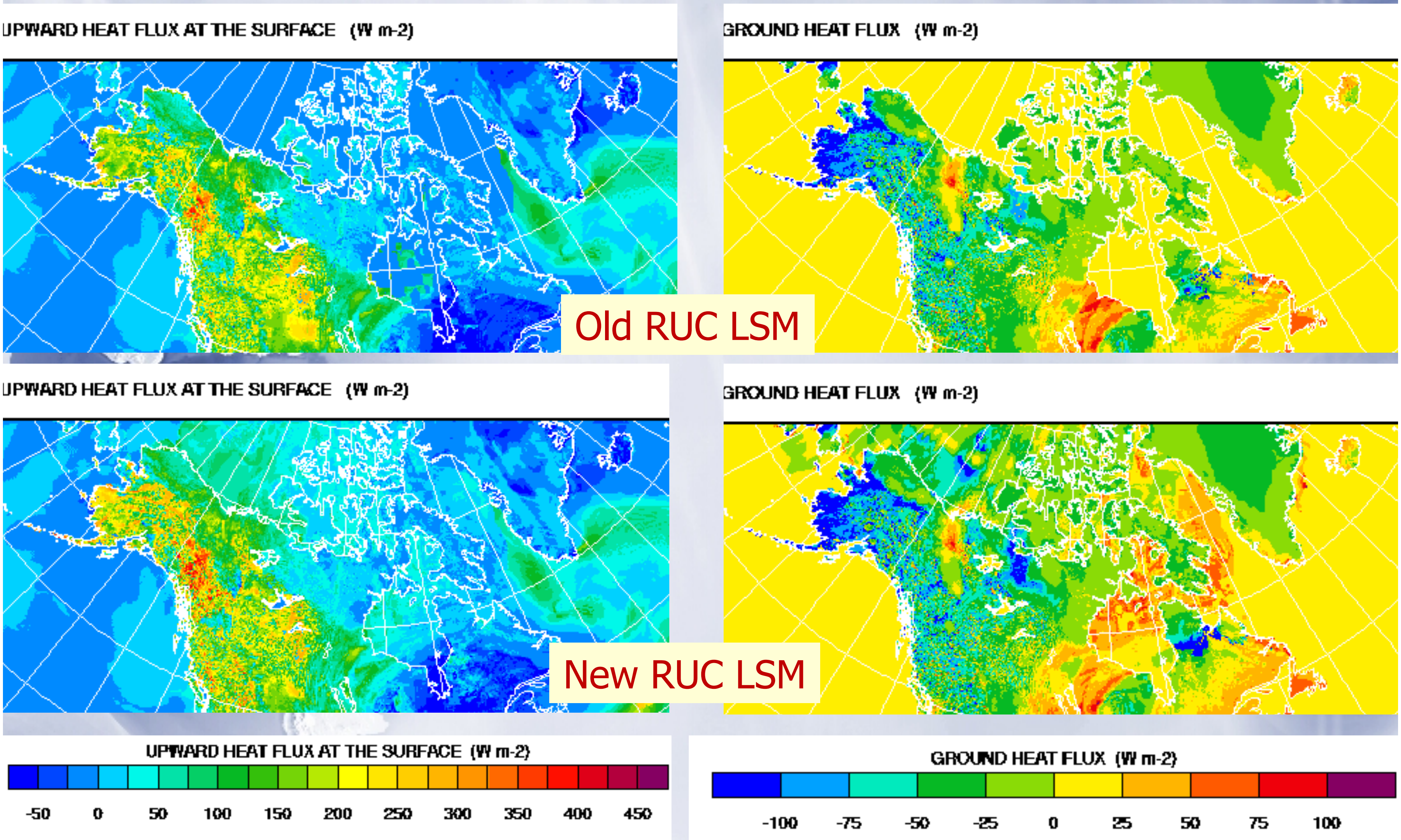




In both Old and New RUC LSM:
Snow albedo – “patchy” snow, albedo reduced when
h snow < h crit (5-10 cm)

In New RUC LSM:
Snow/sea ice albedo is reduced when
T snow/ice > -10 C
Minimum values for snow/ice when T = 0 C

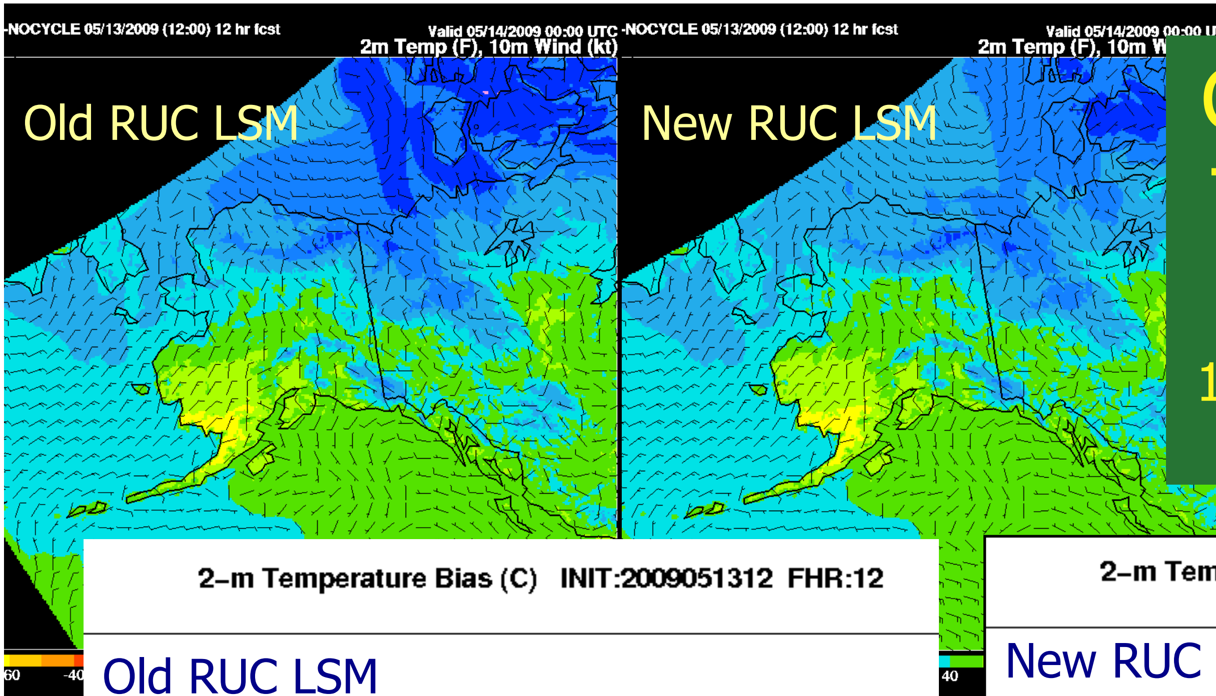
Surface Sensible and Ground Heat Fluxes

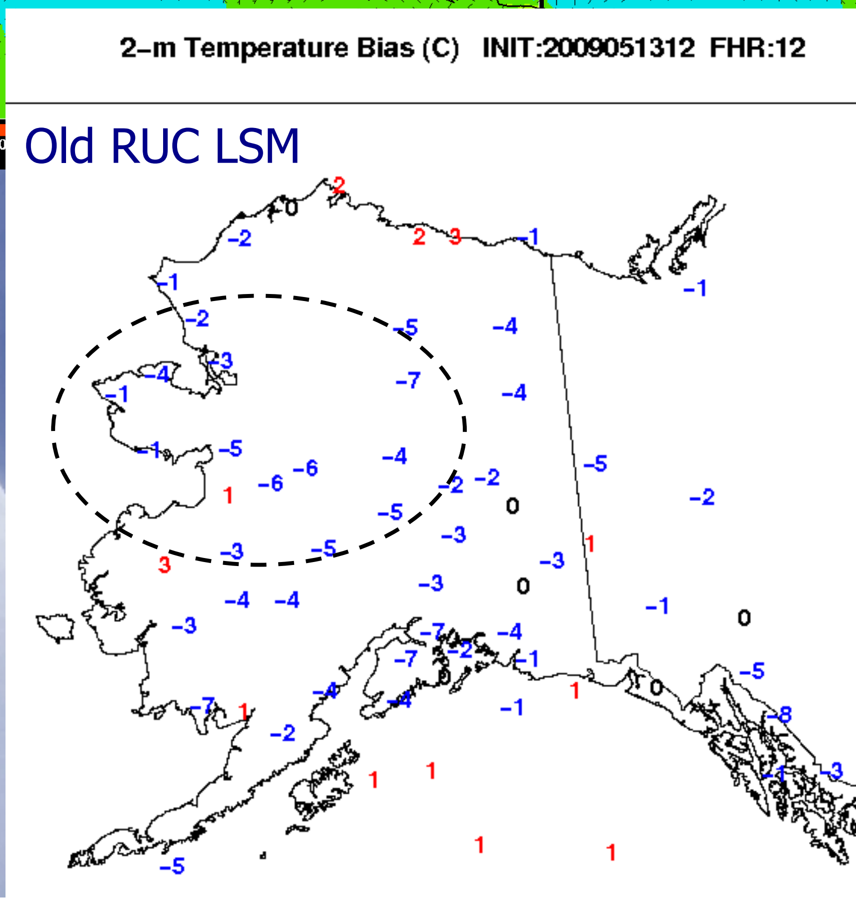


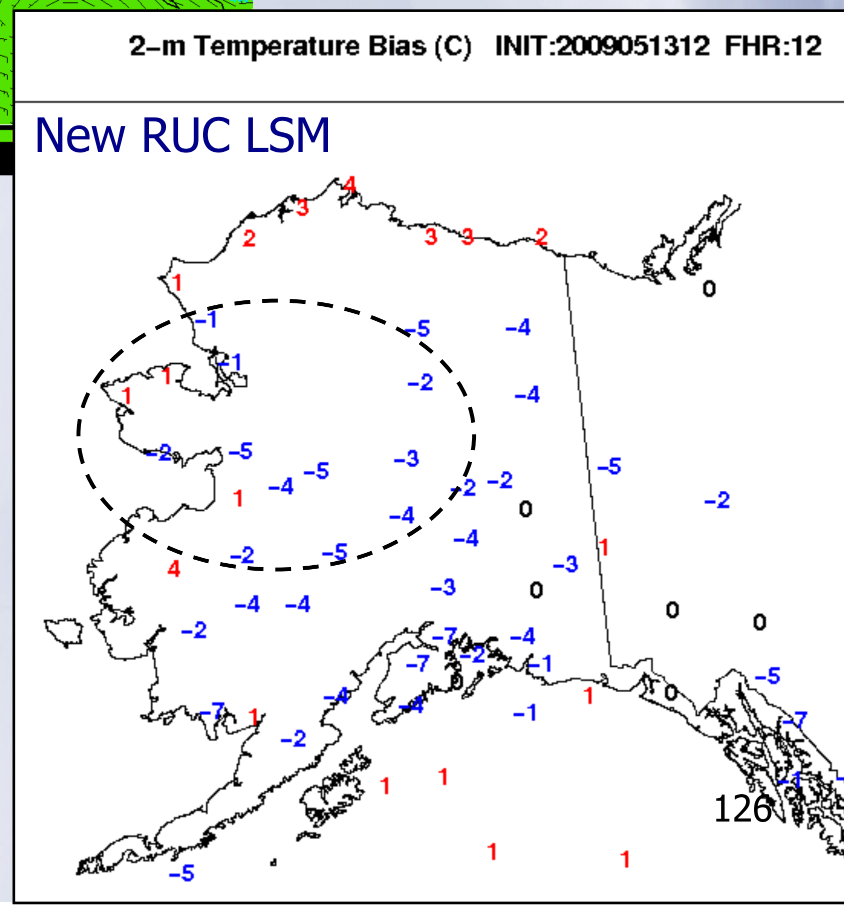
Cold-start RR 12-h forecast valid at 00 UTC, 14 May 2009

Cold-start RR 2-m Temperature bias for Alaska

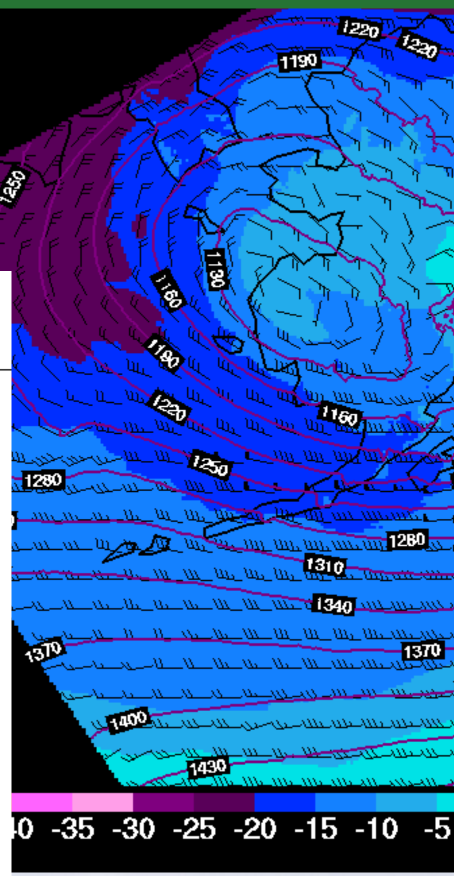
12-h forecast valid at 00 UTC 14 May 2009

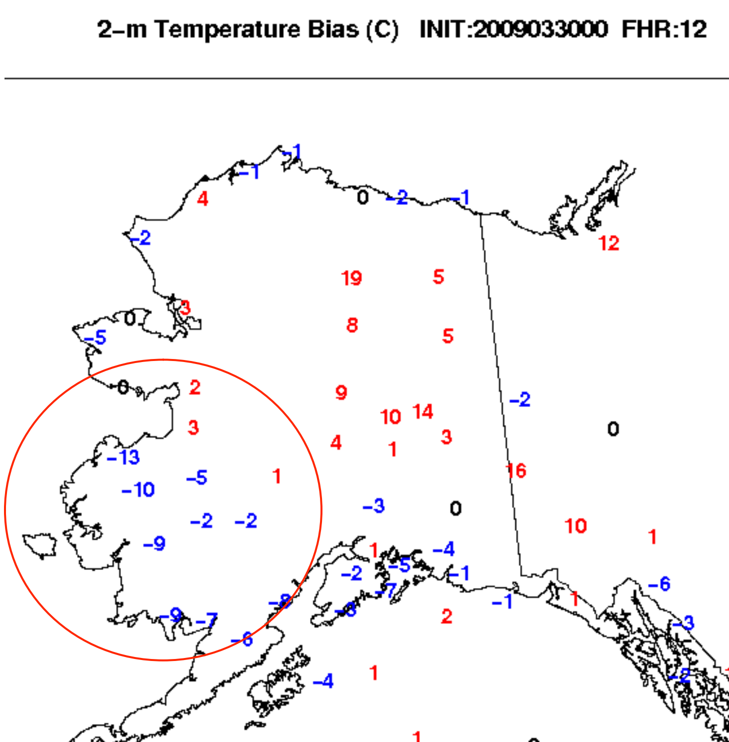




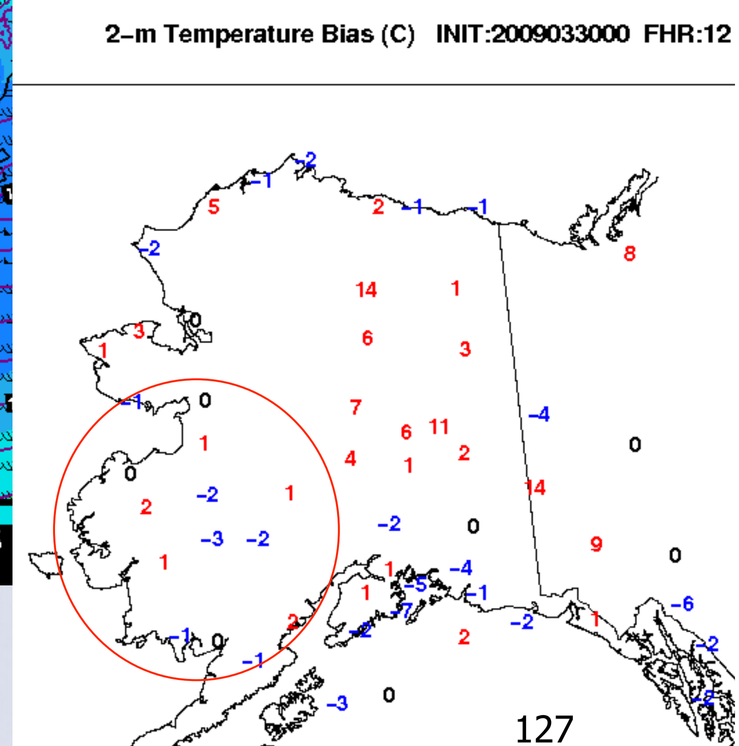


2-m temperature verification for Alaska, 12h forecast valid at 12 UTC 30 March 2009





Old RUC LSM

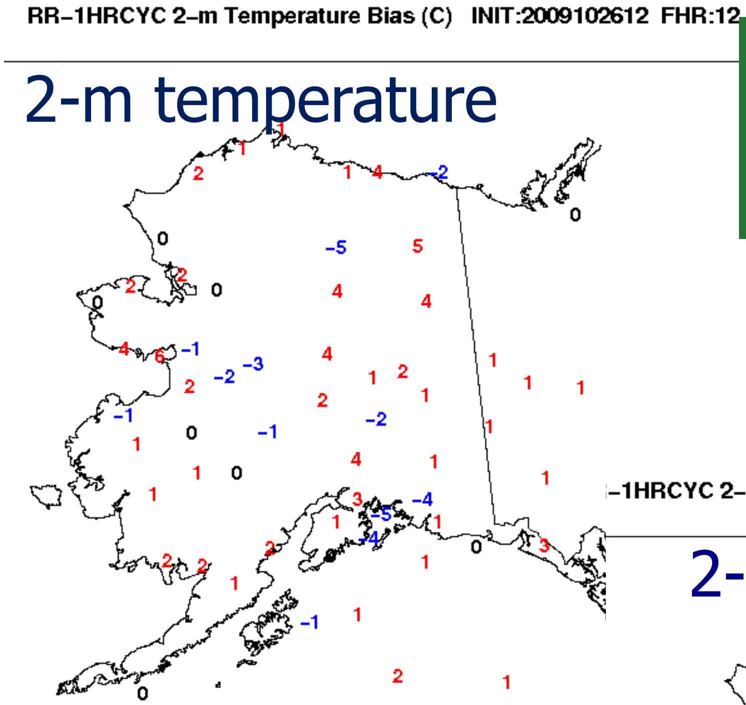


New RUC LSM

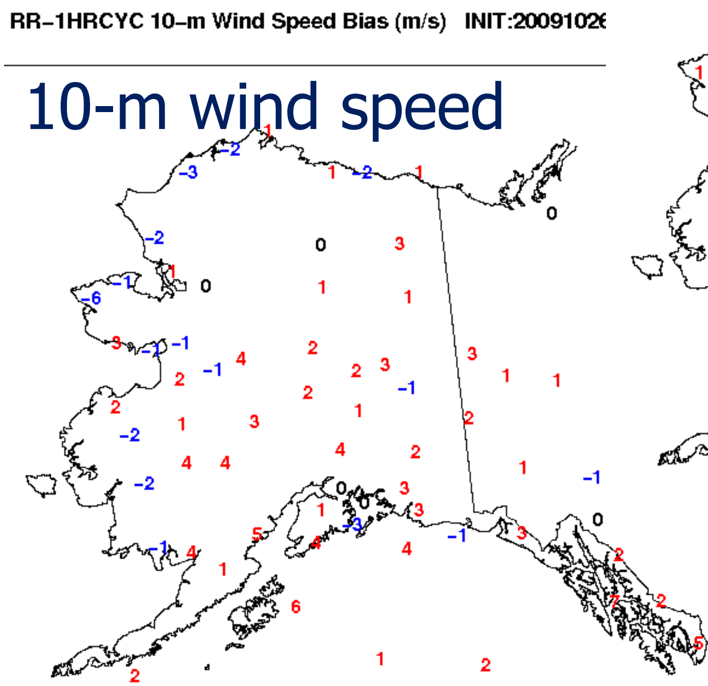
Cycled RR Surface Verification for Alaska

Cycling with New RUC LSM since 24 April 2009, modifications to surface diagnostics

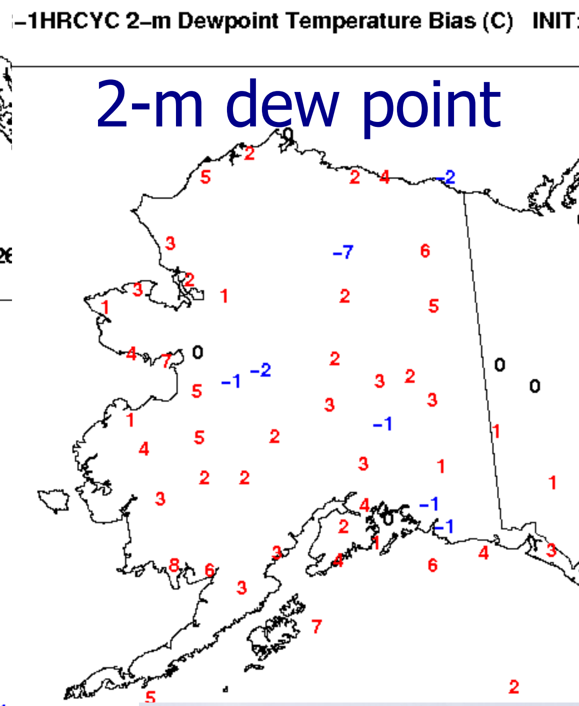
2-m temperature

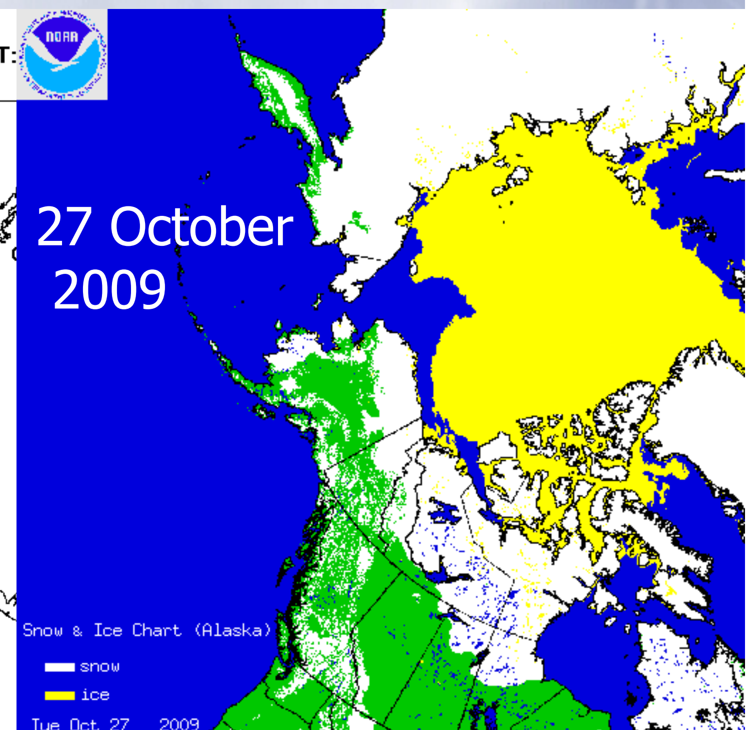


10-m wind speed



2-m dew point



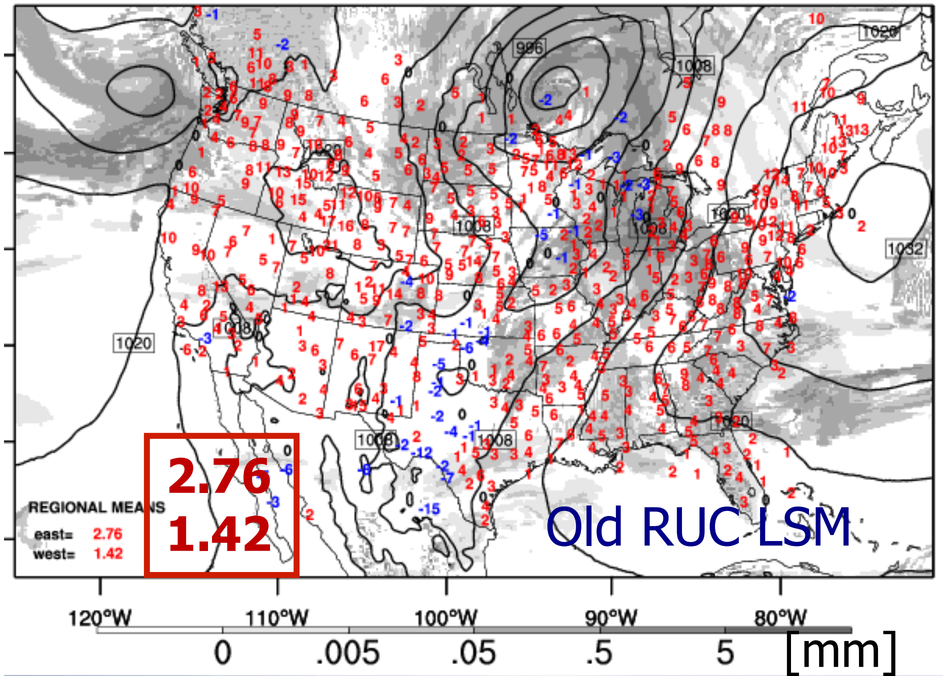


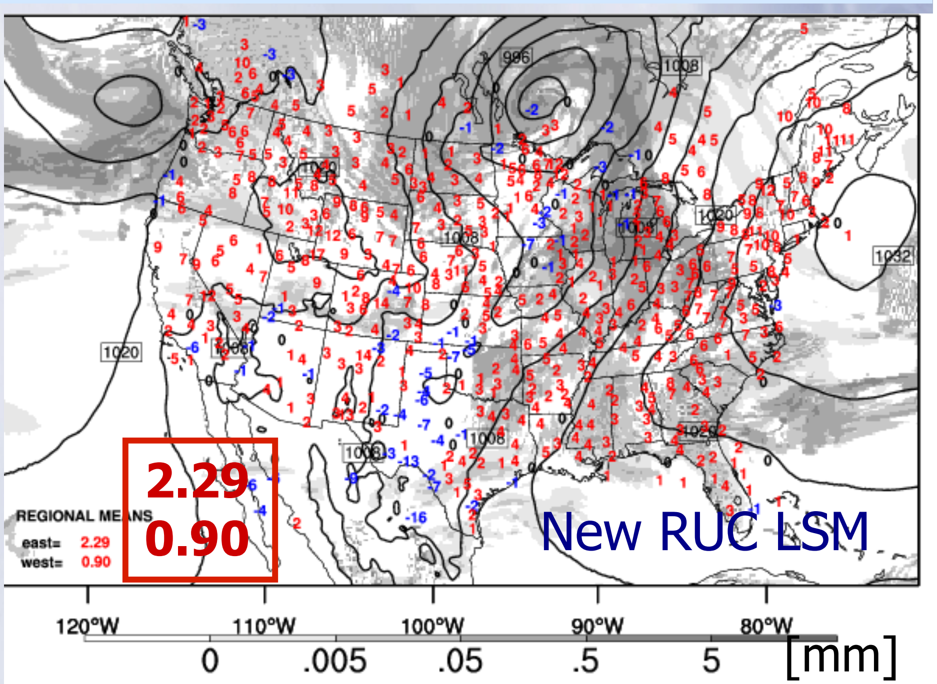
27 October 2009

Valid at 00 UTC 27 October 2009

Cold-start RR 2-m dew point temperature verification

- Corrections to RUC LSM coupling with the PBL schemes in the WRF framework
- Mostly affected moisture exchange between ground surface and the atmosphere during the daytime

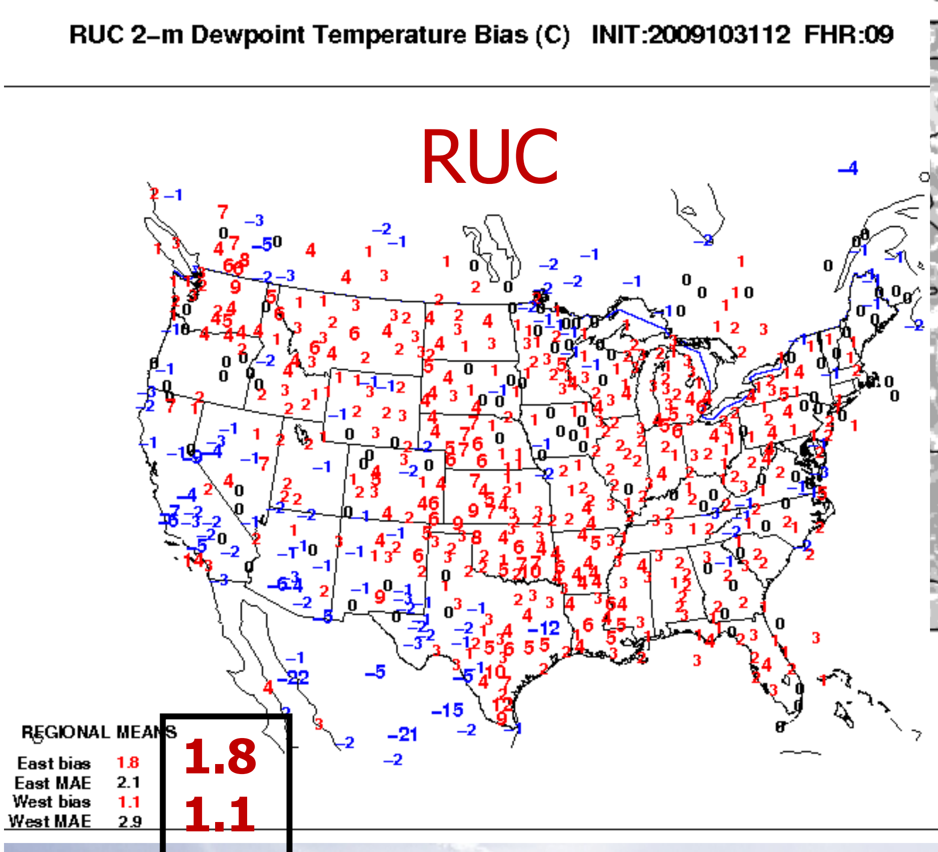


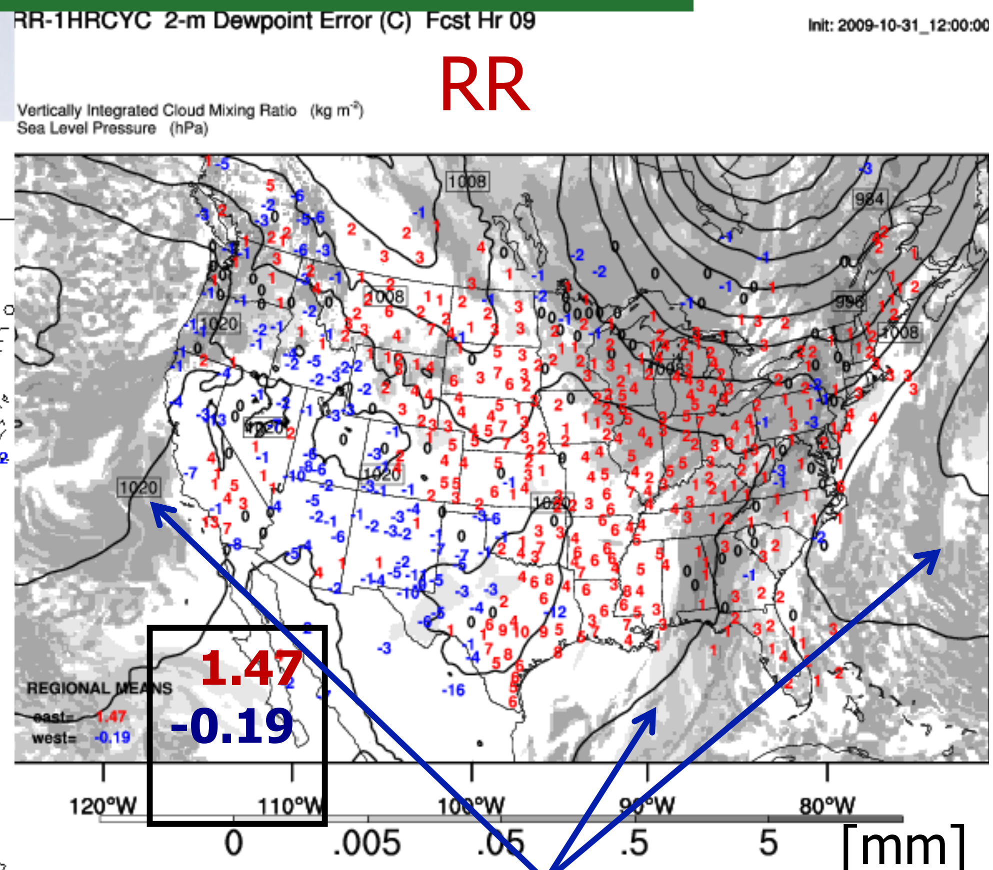


Shading - vertically integrated cloud water and ice mixing ratio

9-h forecast valid at 21 UTC 13 May 2009

Cycled RR 2-m dew point verification compared to RUC

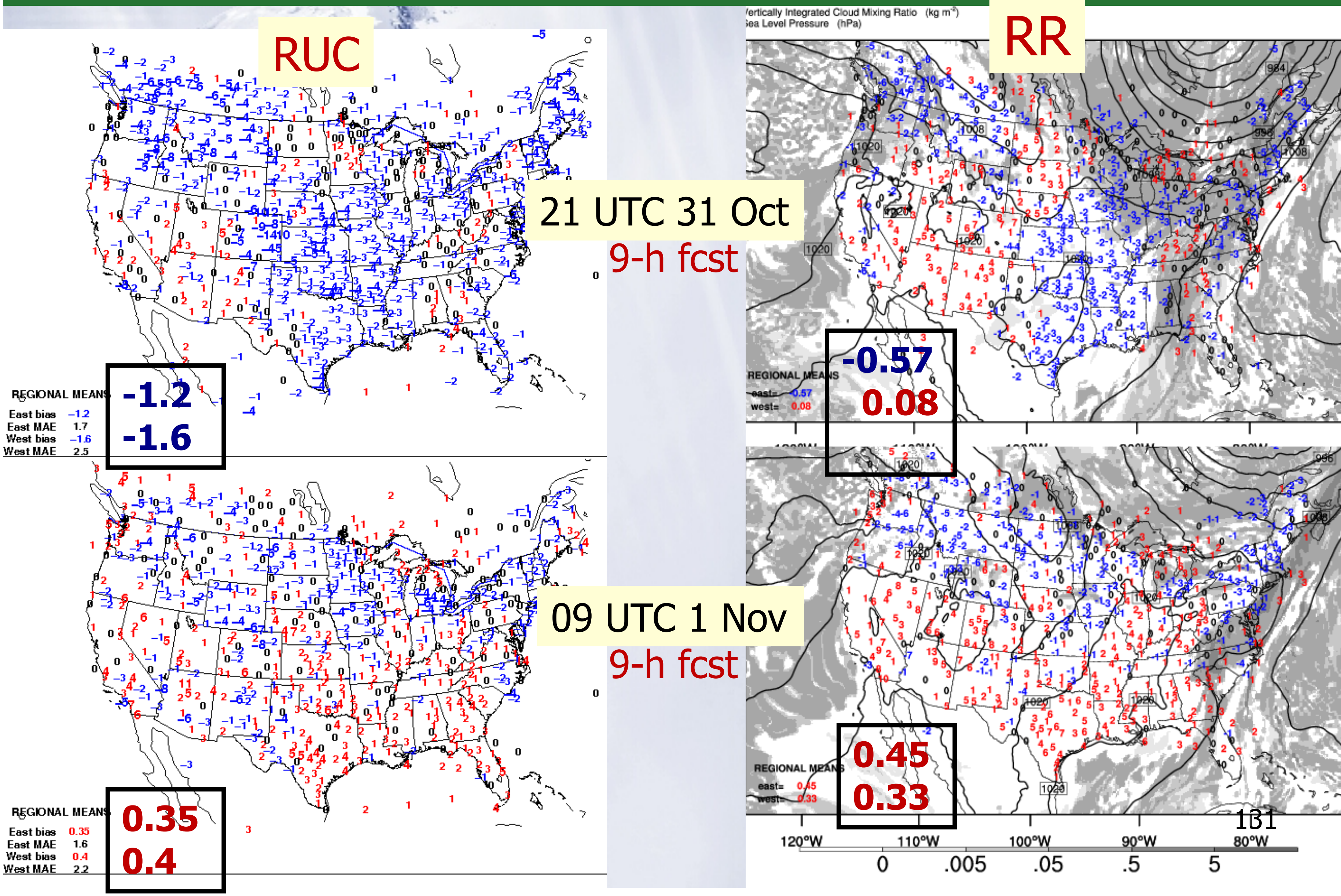




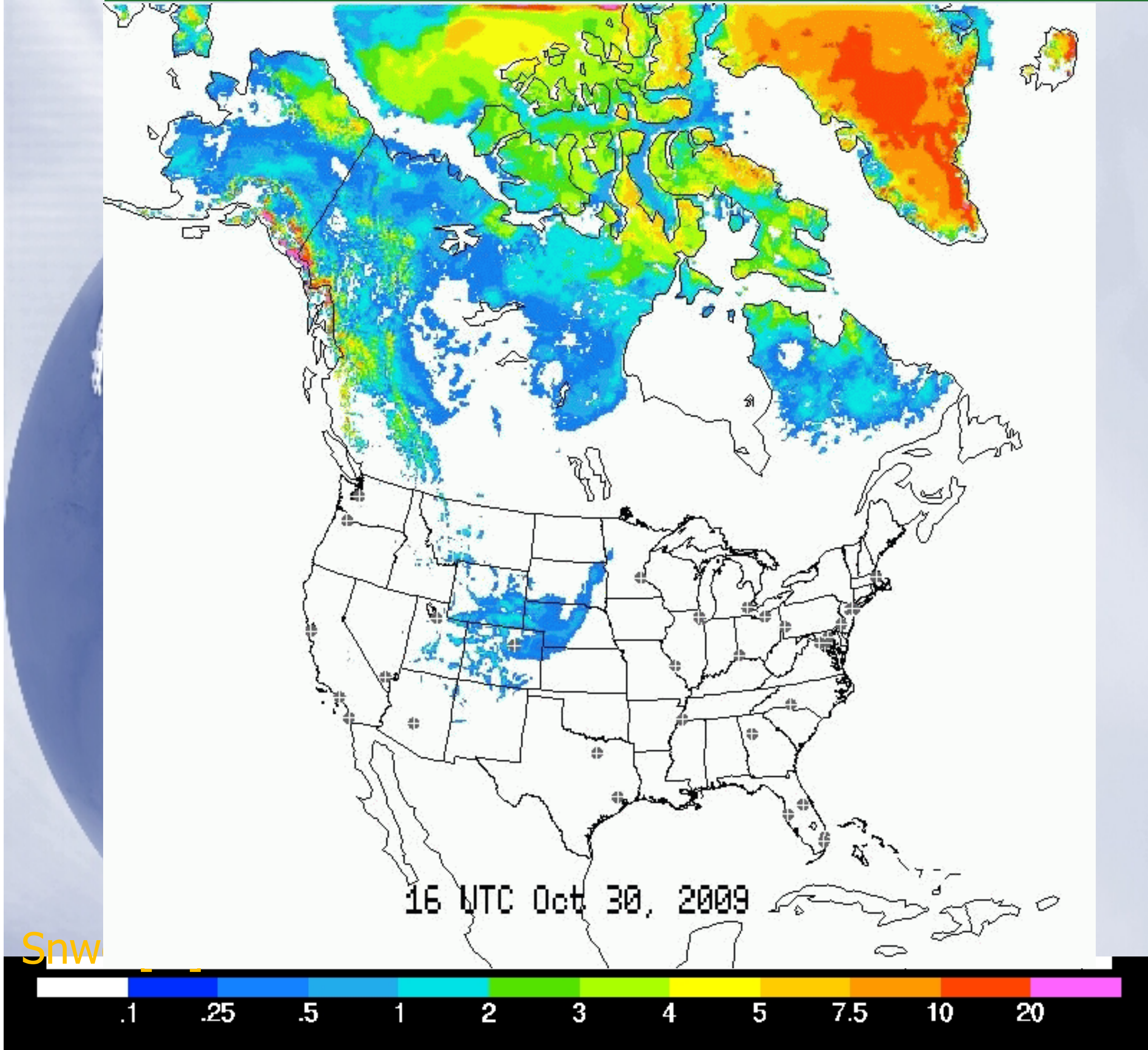
Shading - vertically integrated cloud water and ice mixing ratio

Valid 21 UTC 31 October 2009

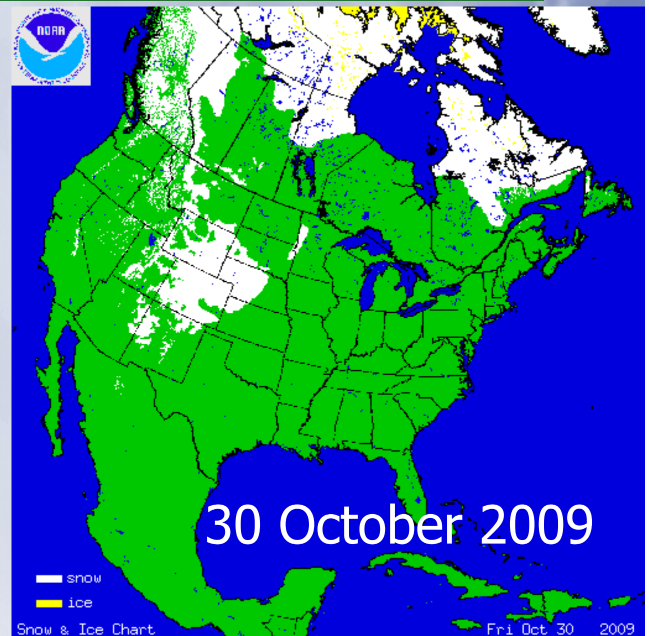
Verification of 2-m temperature diurnal cycle in RR compared to RUC

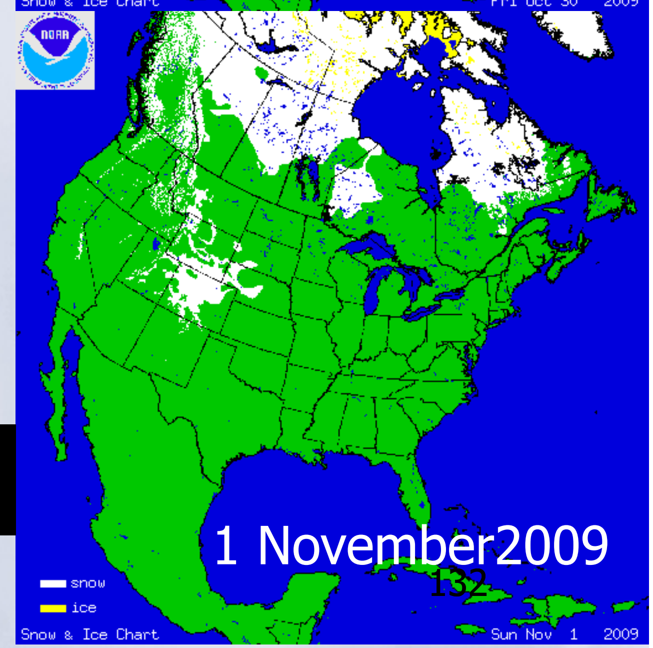


Snow cycling in 1-hour cycled Rapid Refresh



Start: 16 UTC October, 30 2009 End: 15 UTC November 1, 2009 (46 snapshots)





WRFPOST modifications

Added new diagnosed variables:

- MAPS Sea Level Pressure
- GSD Cloud bottom height
- GSD Cloud Top Height
- GSD visibility
- GSD Relative humidity
- Thompson Reflectivity

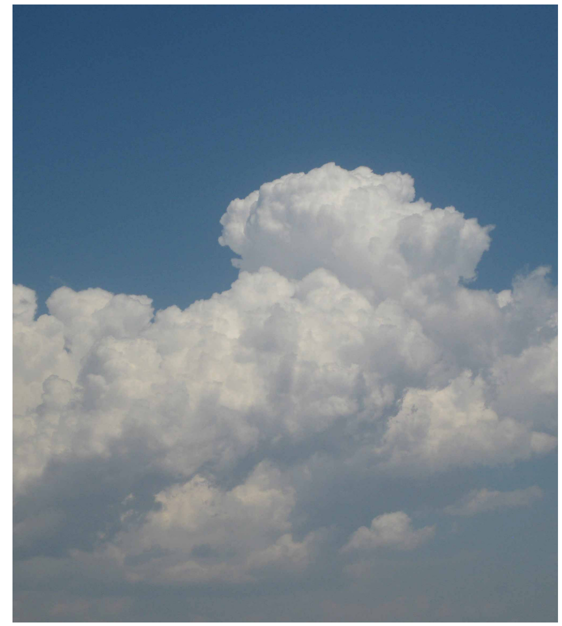
Collaboration with NCEP (Hui-ya Chang) to get these modifications into Unified WRFPOST

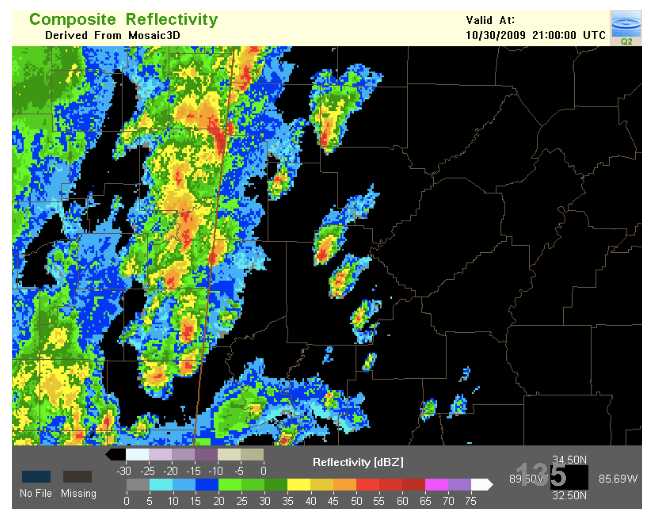
Rapid Refresh / RUC Technical Review - OUTLINE

1:30 – 1:45	RUC➔RR transition overview, NCEP RUC changes – 2008-09-	Stan Benjamin
1:45 – 2:00	Observation impact experiments - TAMDAR aircraft obs w/ moisture, larger OSE	Bill Moninger
2:00 – 2:20	Rapid Refresh overview, assimilation –	Steve Weygandt, Ming Hu
2:20 – 2:30	-- Break --	
2:30 – 3:05	RR-WRF model development / testing – physics, cloud, chemistry, PBL	John Brown, Tanya Smirnova, Joe Olson
3:05 – 3:20	The HRRR and HCPF (HRRR prob forecast)	Curtis Alexander
3:20 – 3:30	Future of RR/HRRR/ens	Stan Benjamin

Very High Resolution Forecasts

- Deep moist convection has low predictability, partly because it occurs on small spatial and temporal scales
- Convective parameterization in RUC and RR not sufficient to reproduce convective-scale structures and evolution
- Need hourly-updating convection-resolving model that can assimilate convective-scale observations -- especially radar -- given sufficient computing resources





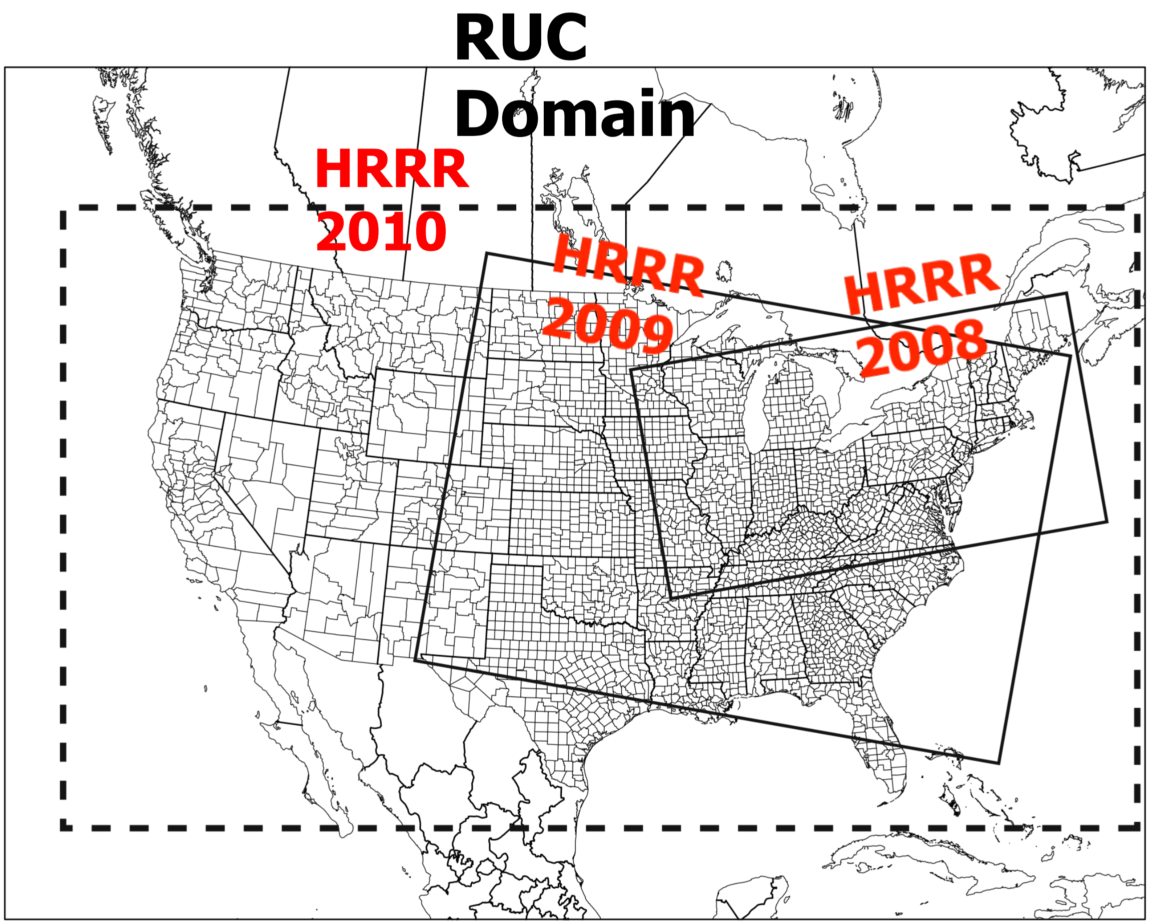
The HRRR

High-Resolution Rapid Refresh (HRRR)

- WRF-ARW dynamic core (same configuration as RR but without convective parameterization)
- Convection resolving using 3.0 km horizontal grid spacing
- Hourly initialization, 0-12 hr forecasts produced (2 hr latency)
- Initial conditions from same-cycle hourly 13 km RUC (RUC13)
- Boundary conditions provided via previous-cycle RUC13

- RUC13 hourly assimilation cycle uses a diabatic digital filter initialization (DDFI) for assimilation of observed radar reflectivity to adjust mass (temperature tendency) and associated momentum fields (divergence) without adjusting hydrometeor distribution

HRRR Domain(s)



September 2007
Initial HRRR domain over the northeastern United States "aviation corridor"
745 x 383 grid points, 200 processors

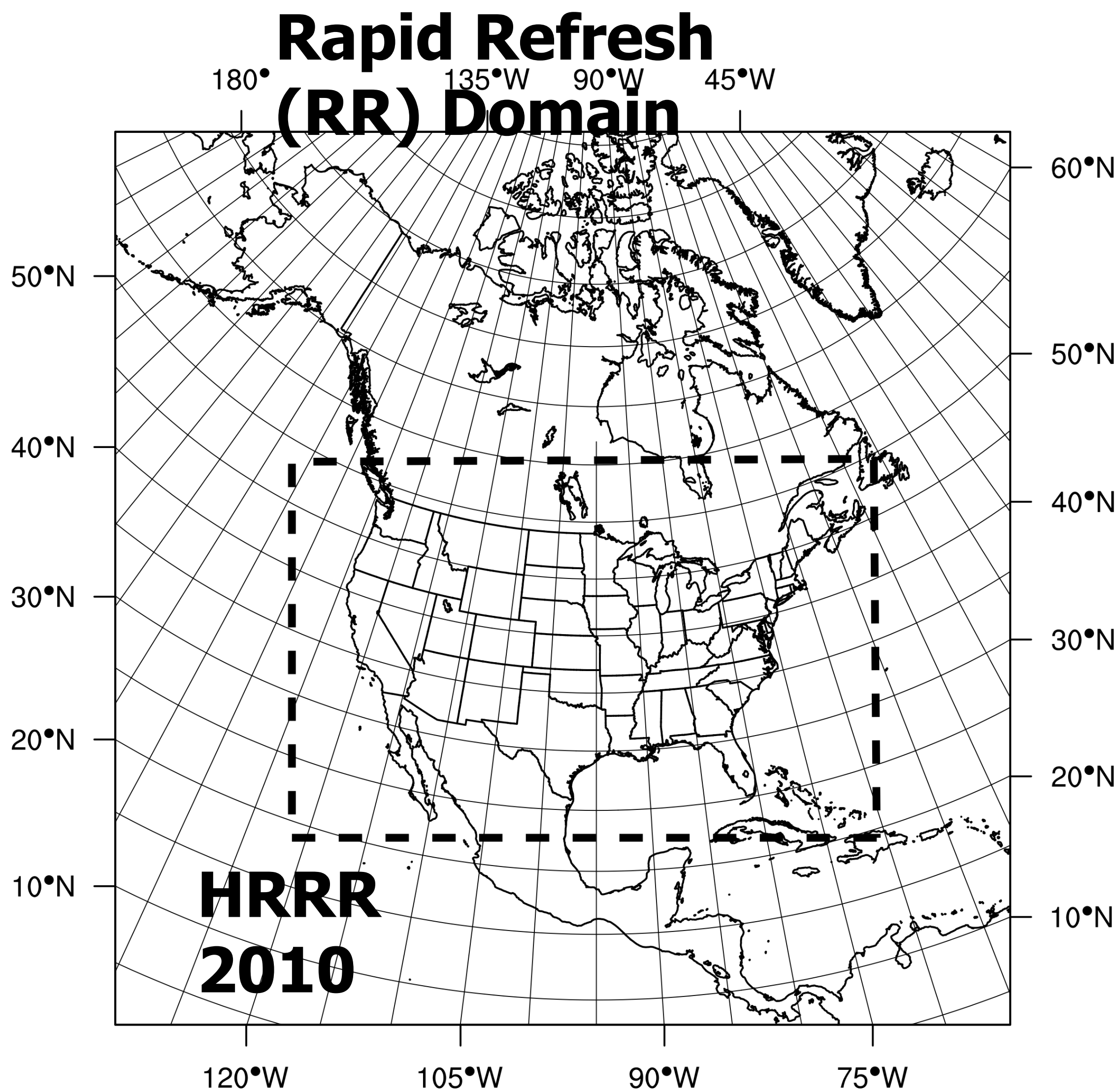
March 2009
Domain expanded to cover approximately eastern 2/3 of the US
1000 x 700 grid points, 568 processors

October 2009
Domain expanded to cover CONUS
1800 x 1060 grid points, 840 processors

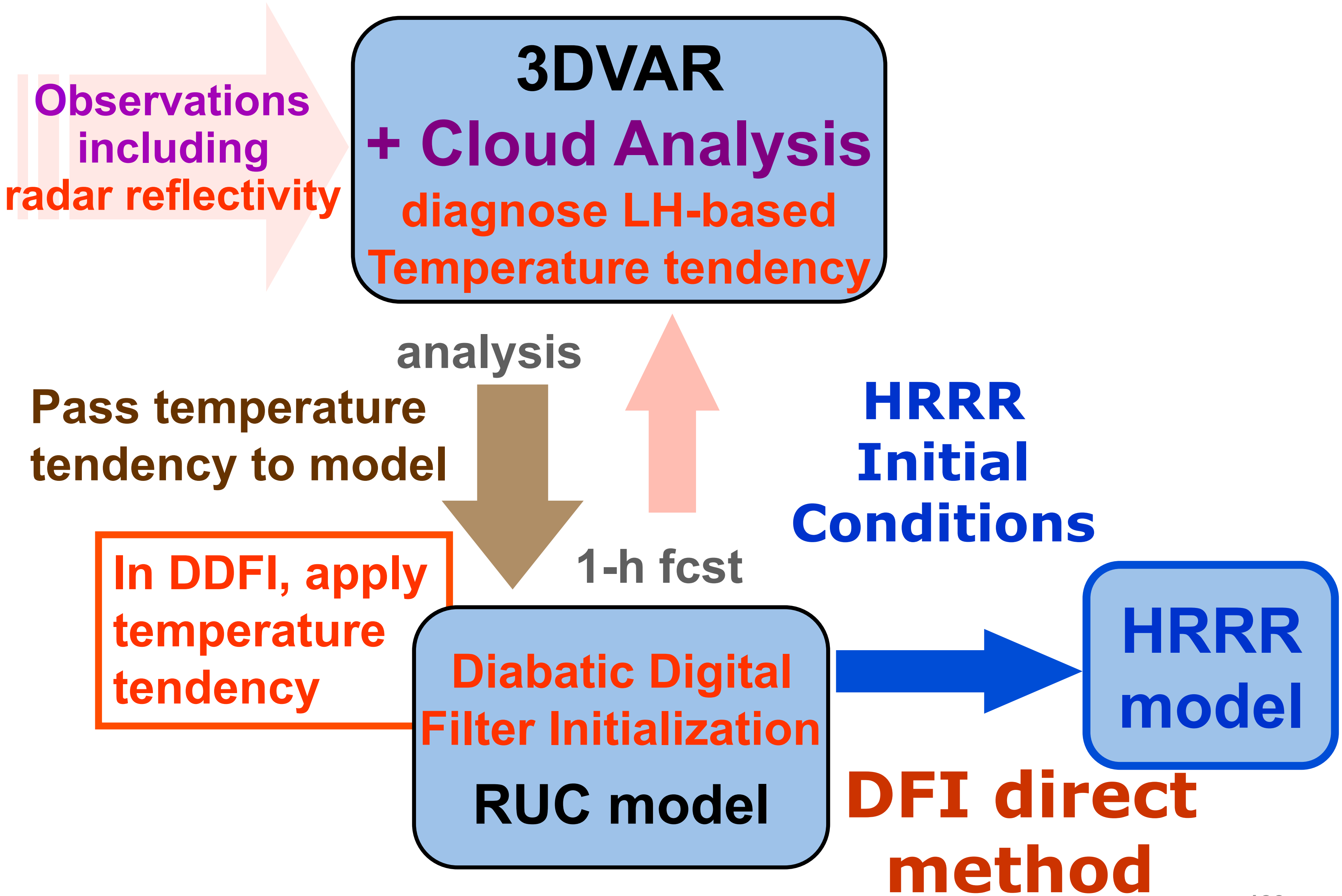
Hourly frequency maintained

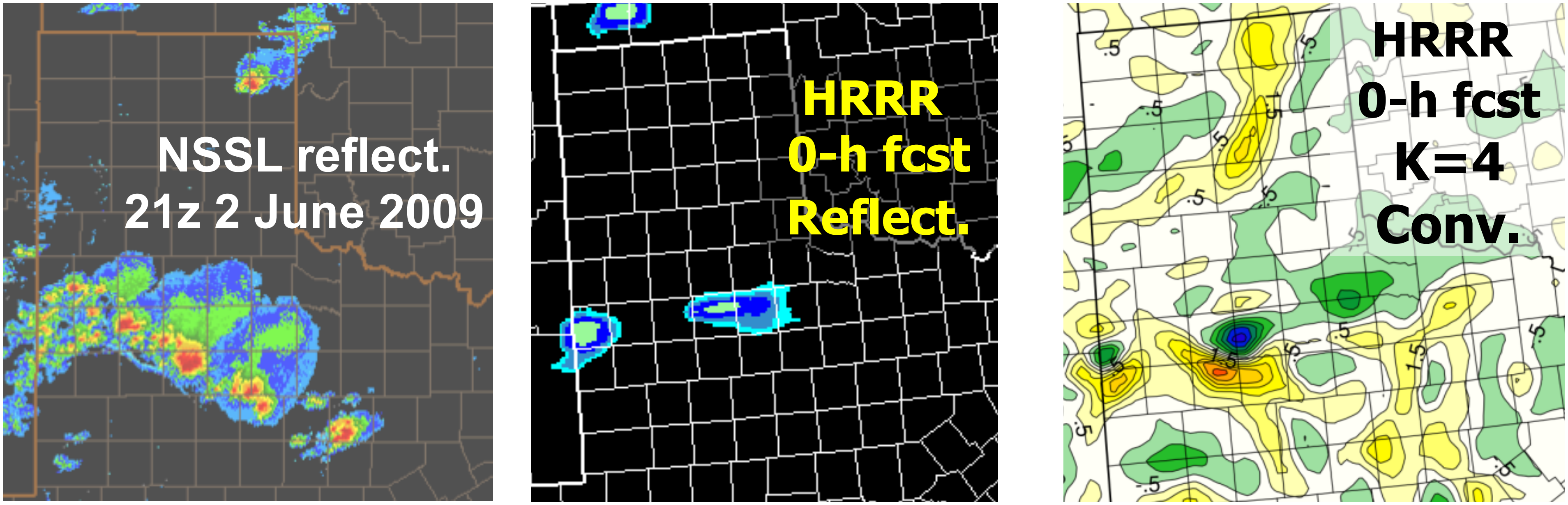
HRRR Domain(s)

Will nest HRRR in RR domain

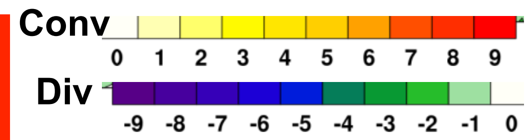


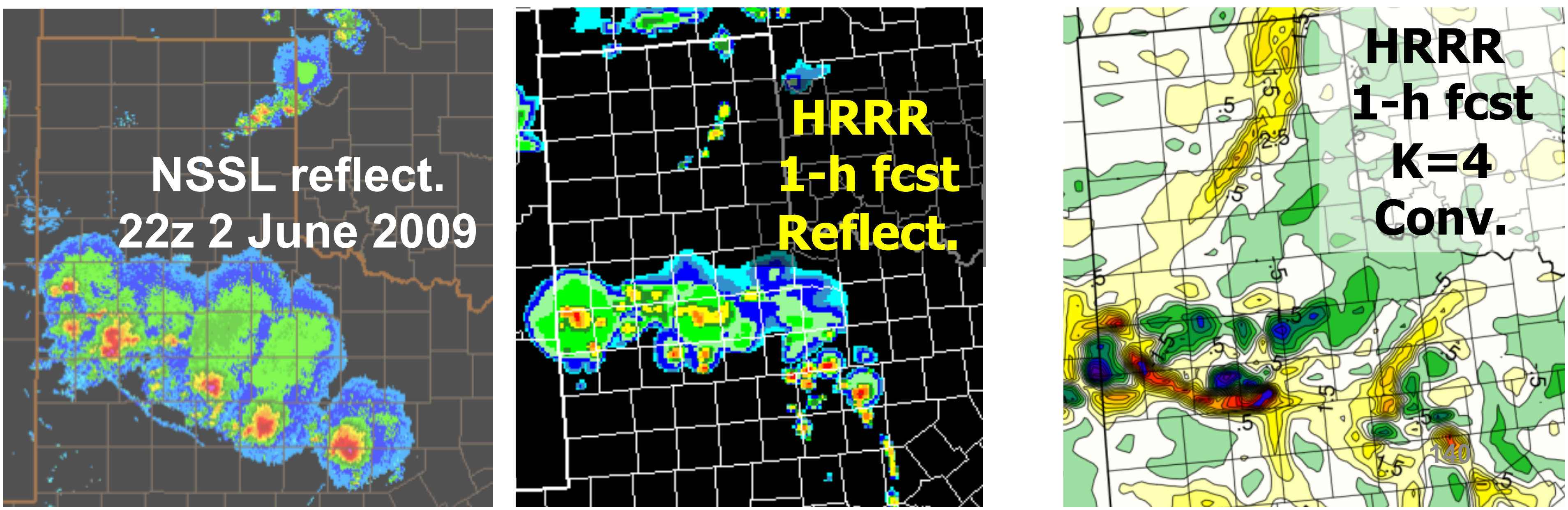
RUC / RR reflectivity assimilation





DFI impact on HRRR fields

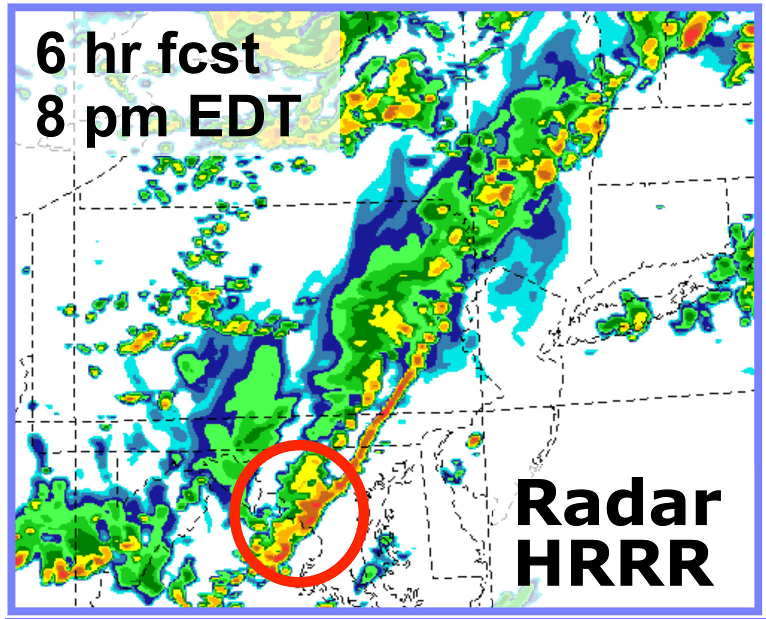




RUC radar assimilation improves HRRR

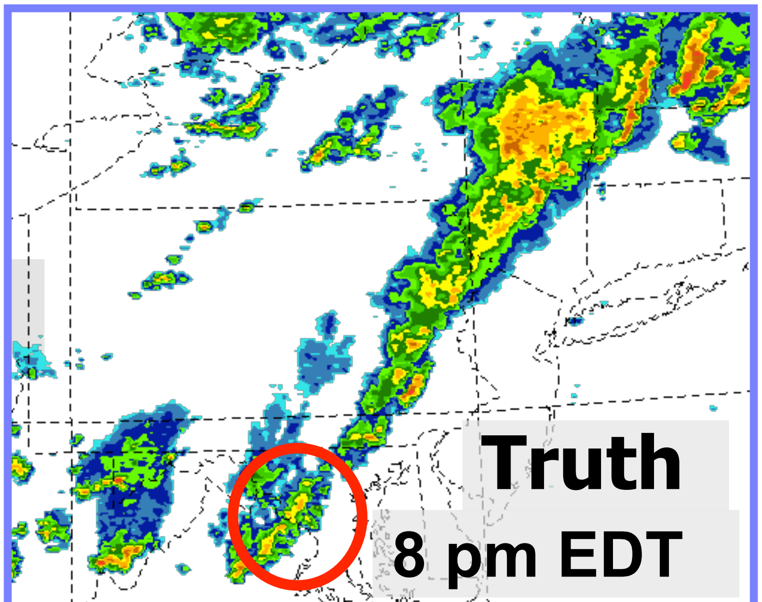
High resolution needed for realistic storm structure (storm-types, line gaps, etc.)

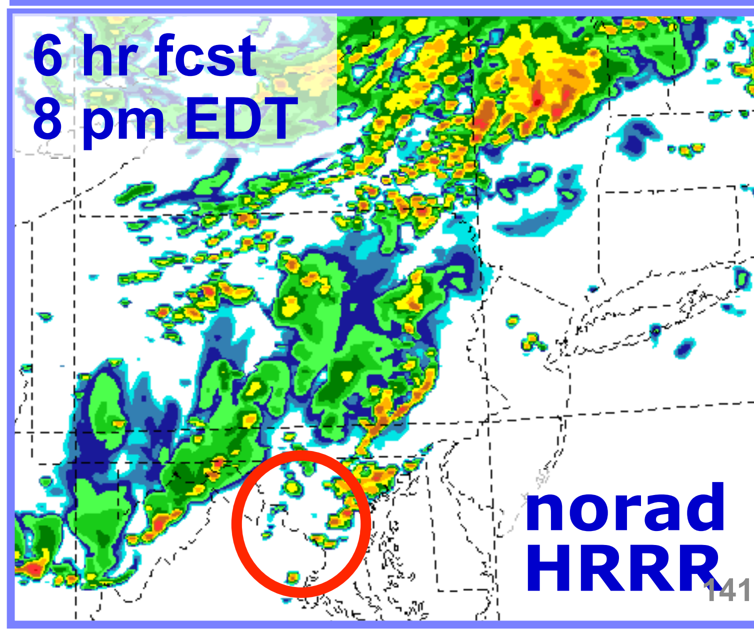
Hourly 12-h forecast, 15-min VIL output



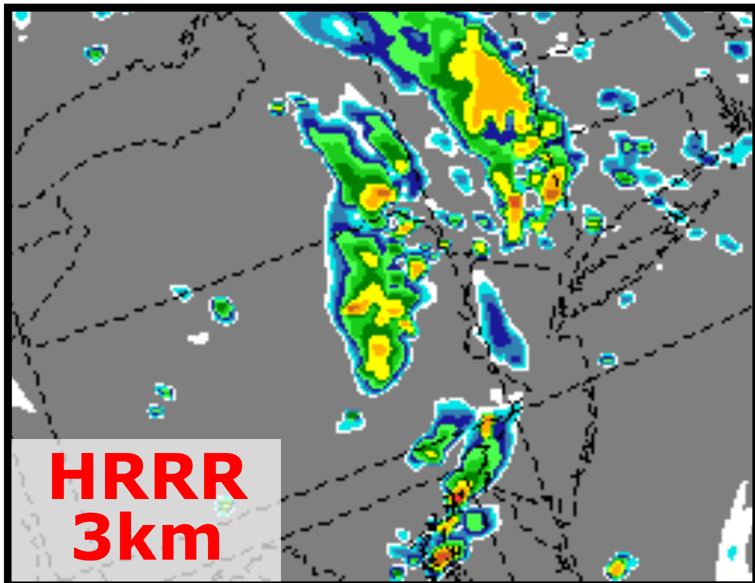
20 July 2008

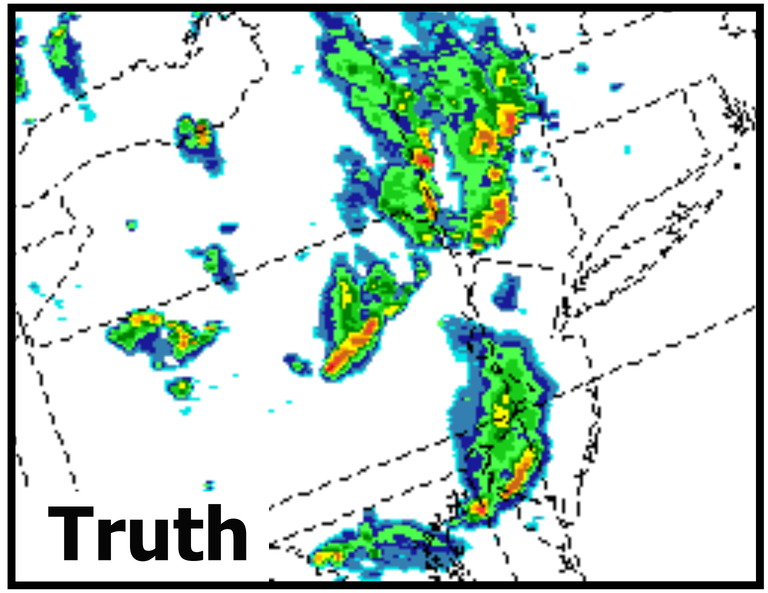
2 pm initial time

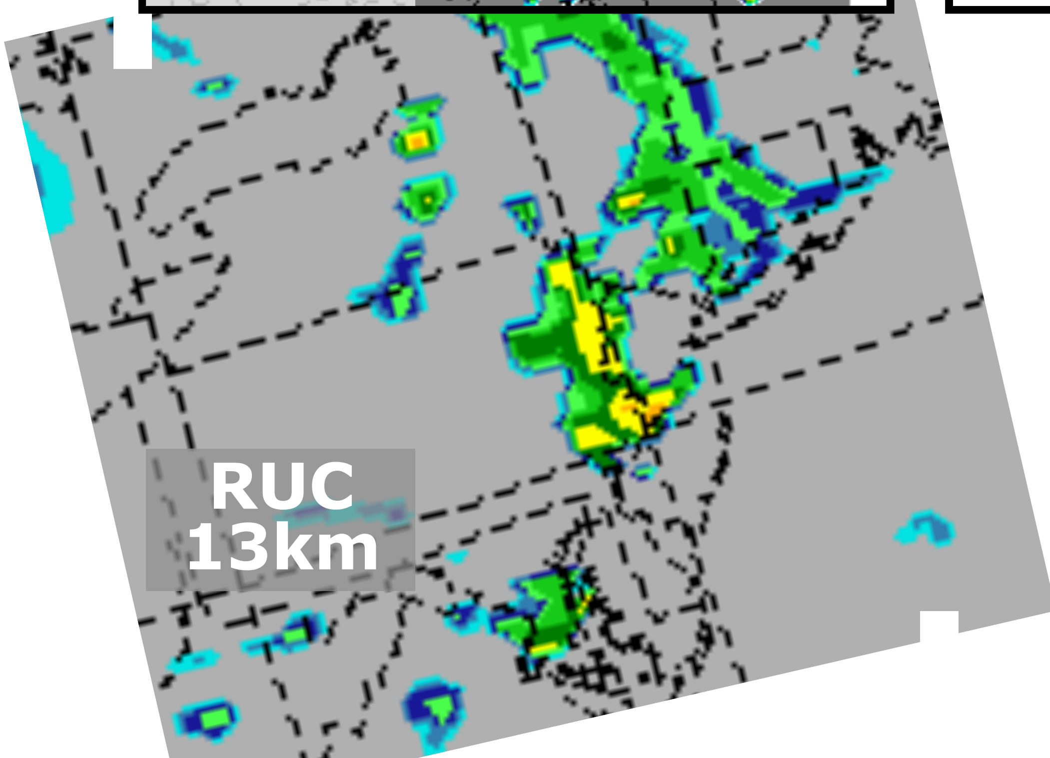




6-h forecasts valid at 8pm EDT 24 July 2008







3km HRRR, improved guidance for ATM, terminal over 13km RUC

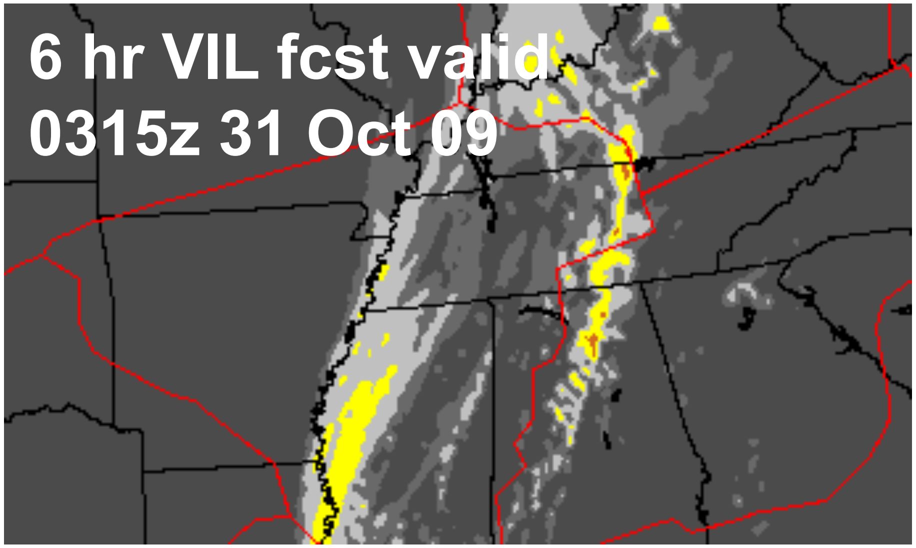
HRRR Users

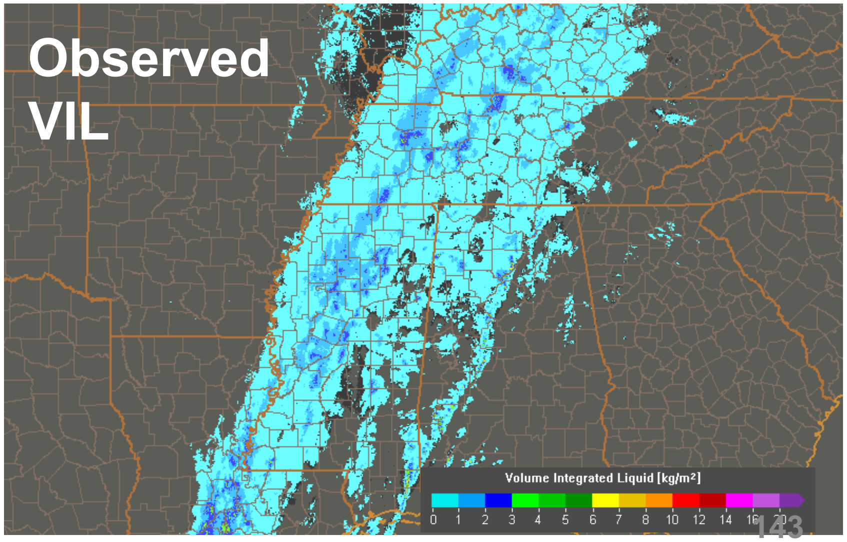
NCAR/MIT-LL/FAA: Consolidated Storm Prediction for Aviation (CoSPA)

NCEP Storm Prediction Center (SPC)

Many NWS forecast offices including Sterling, VA which referenced use 60 times in 15 month period

GSD/FAB Hydromet Testbed

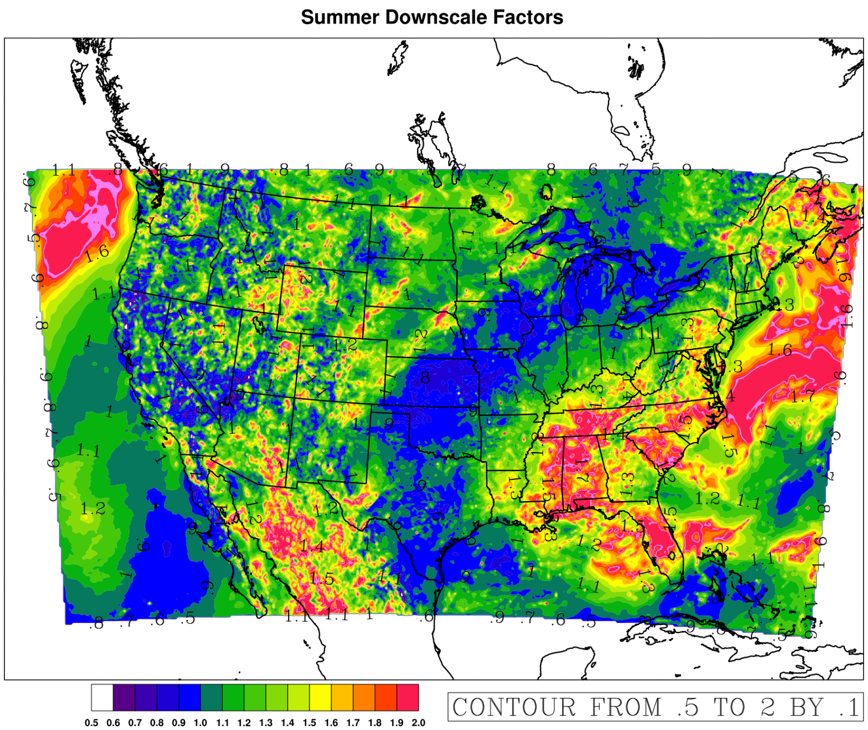


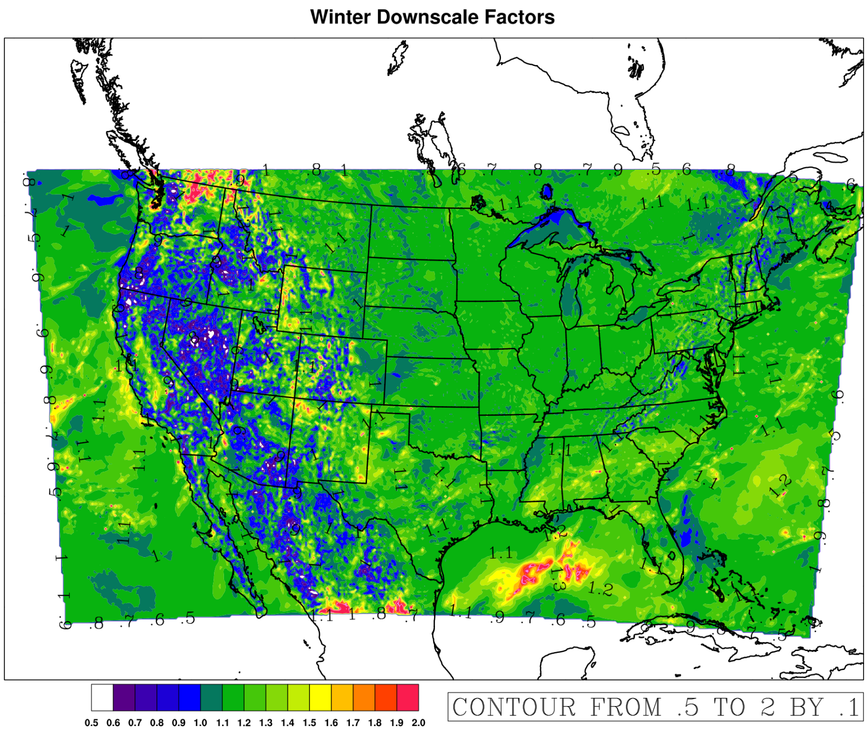


HRRR Users

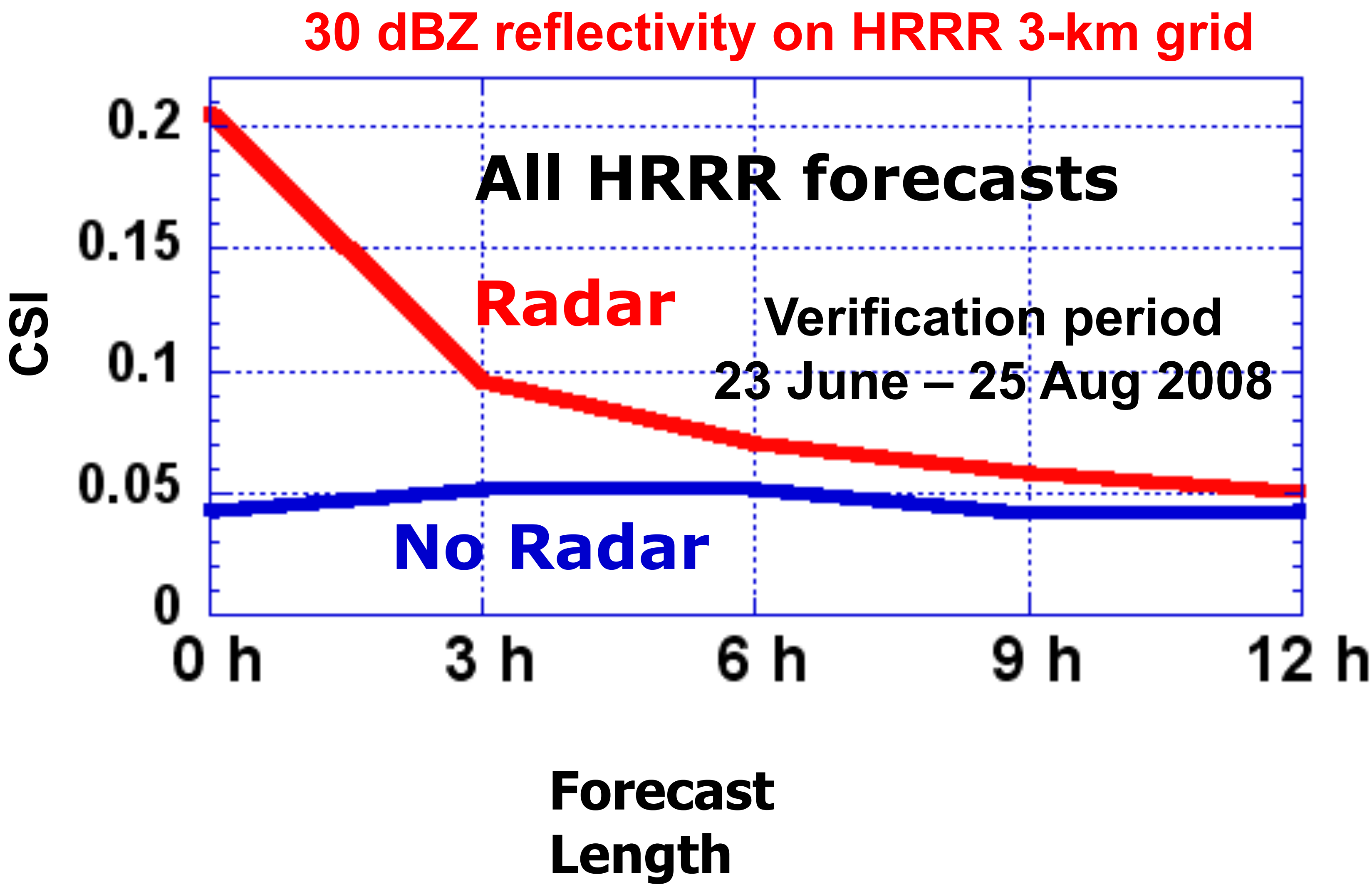
Renewable Energy - Scaling factors of wind speeds at turbine height (80 m AGL) from 42 RUC to HRRR fcsts in each season

HRRR faster winds (yellow-red) in low-terrain in summer
HRRR slower winds (purple-blue) in high-terrain in winter



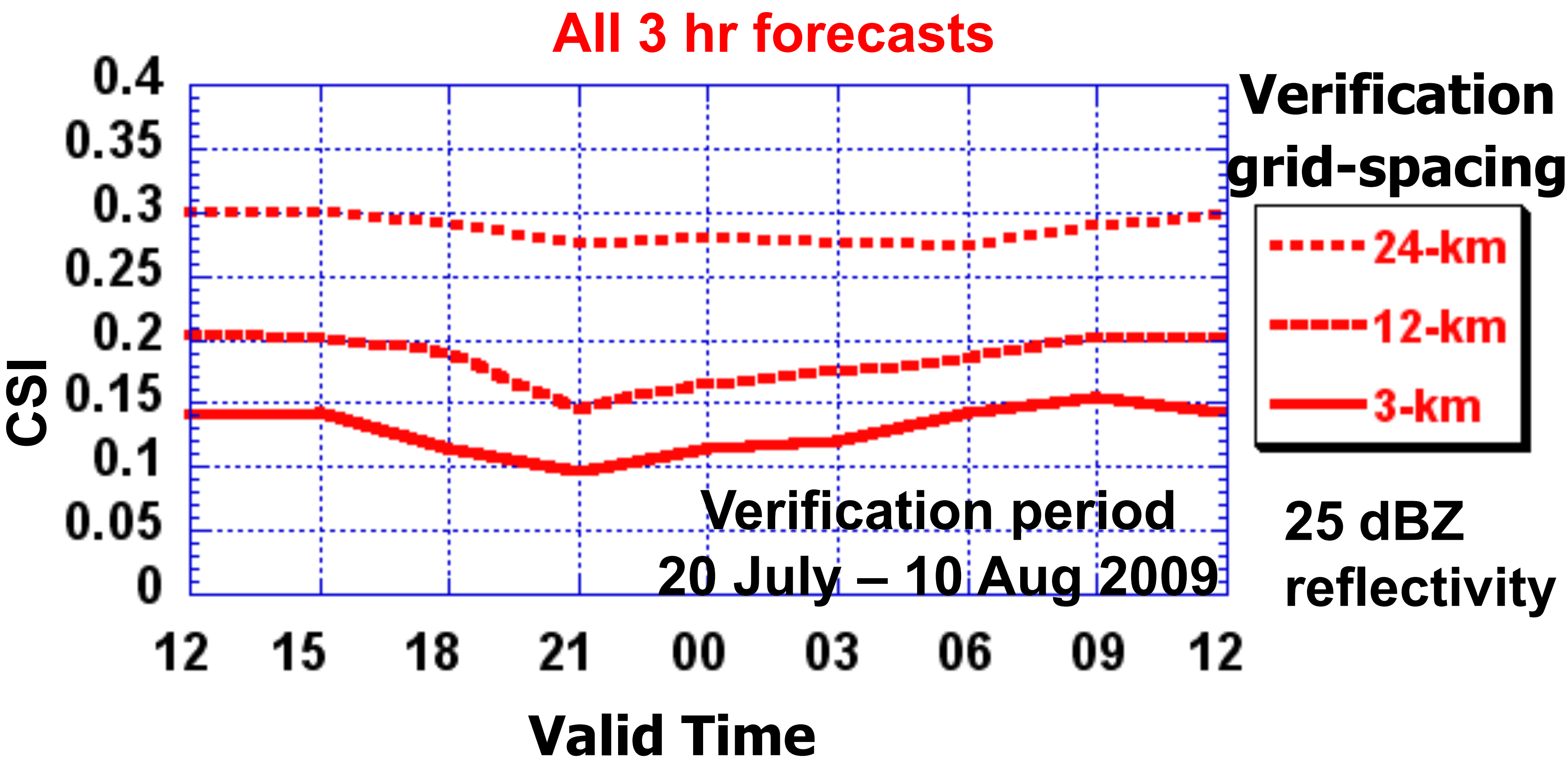


HRRR reflectivity verification skill vs. forecast length

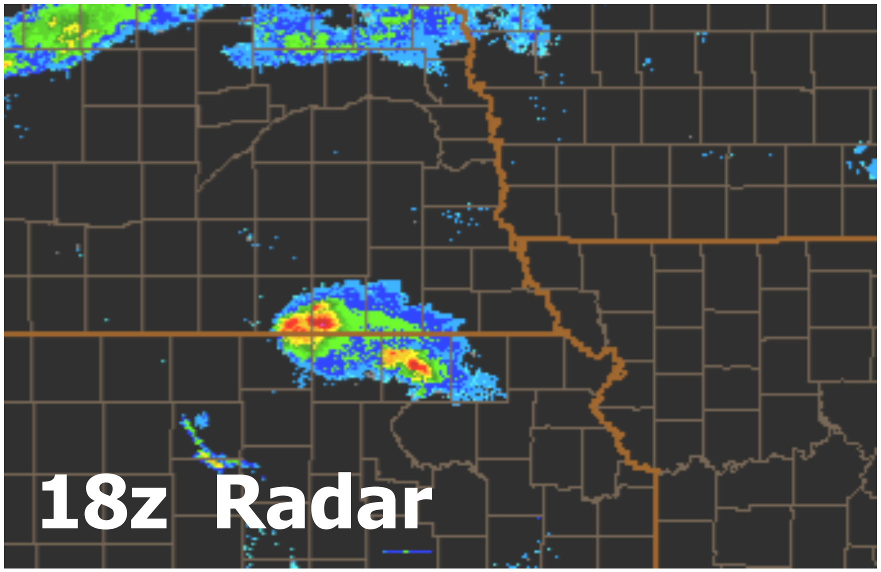


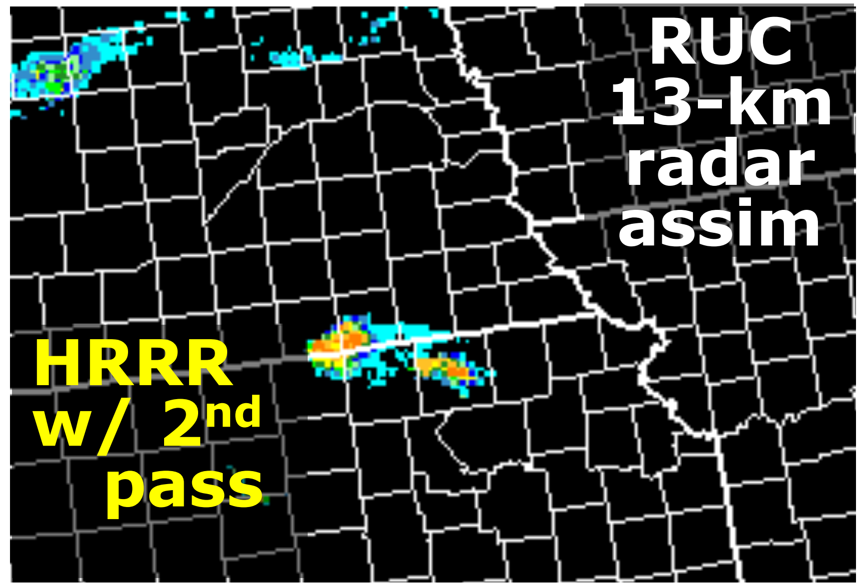
HRRR reflectivity verification with coarser grid

- Higher CSI
- Decreased diurnal effect



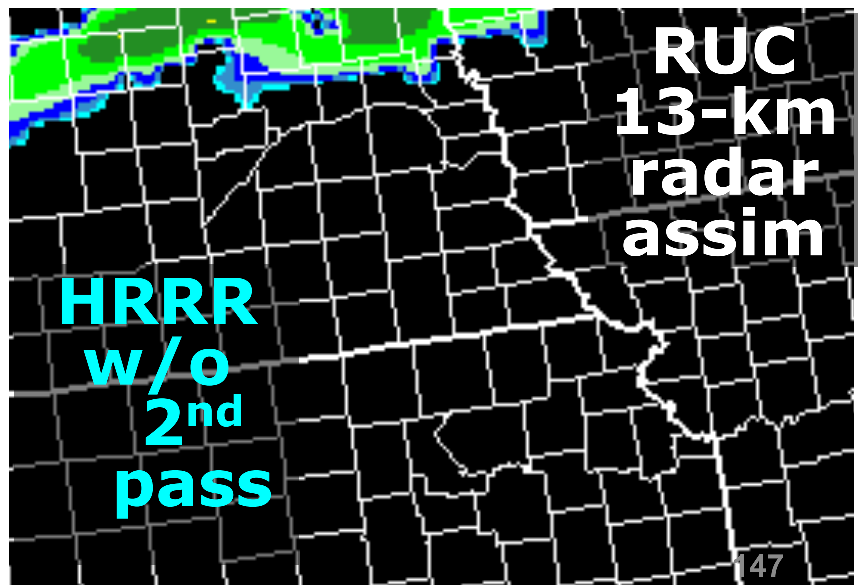
HRRR with 2nd pass radar DA on 3-km domain





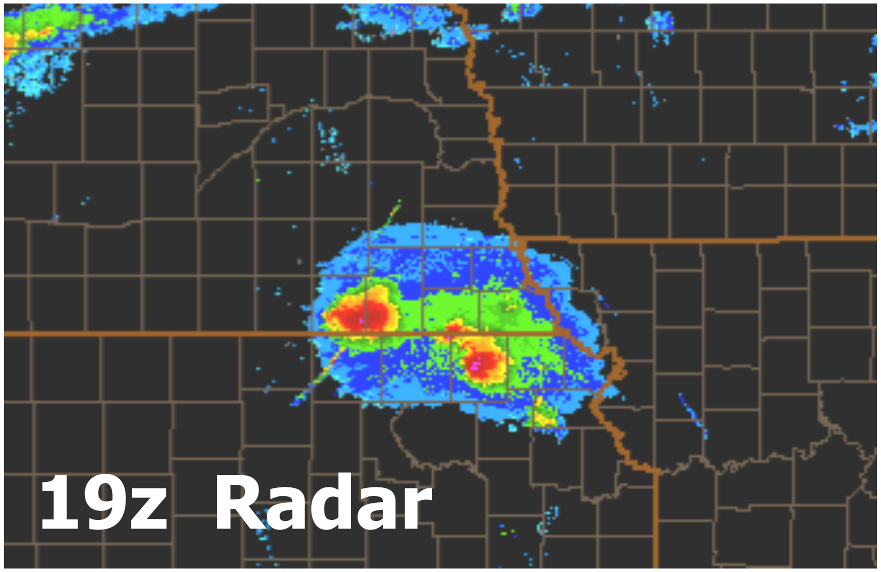
27 June 2009

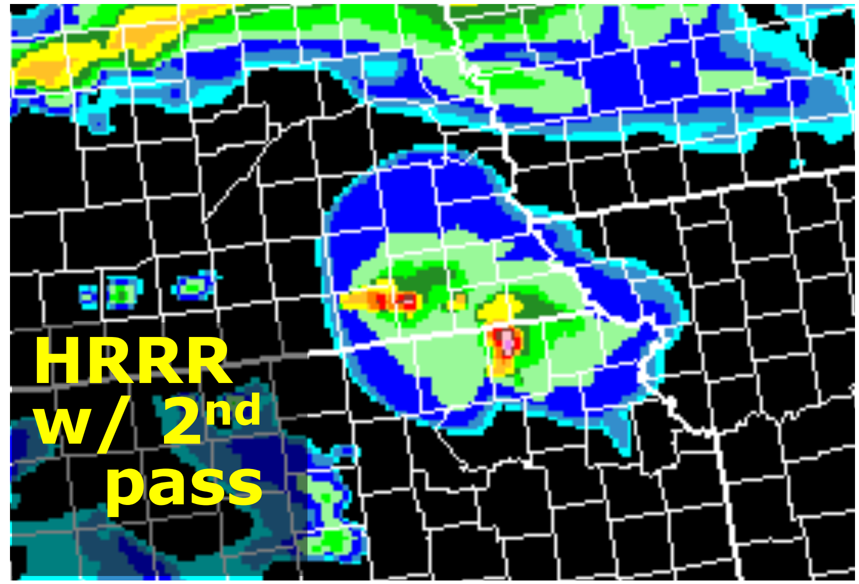
+ 0h
fcsts



- Both forecasts have RUC 13-km DFI reflectivity assim.
- 2nd pass (3-km DFI radar DA) greatly reduces initial spin-up

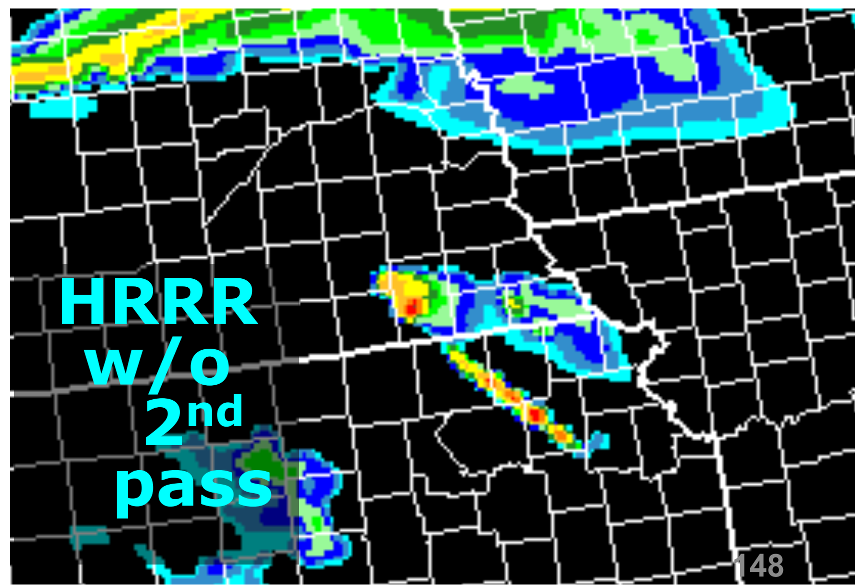
HRRR with 2nd pass radar DA on 3-km domain





27 June 2009

+ 1h
fcsts



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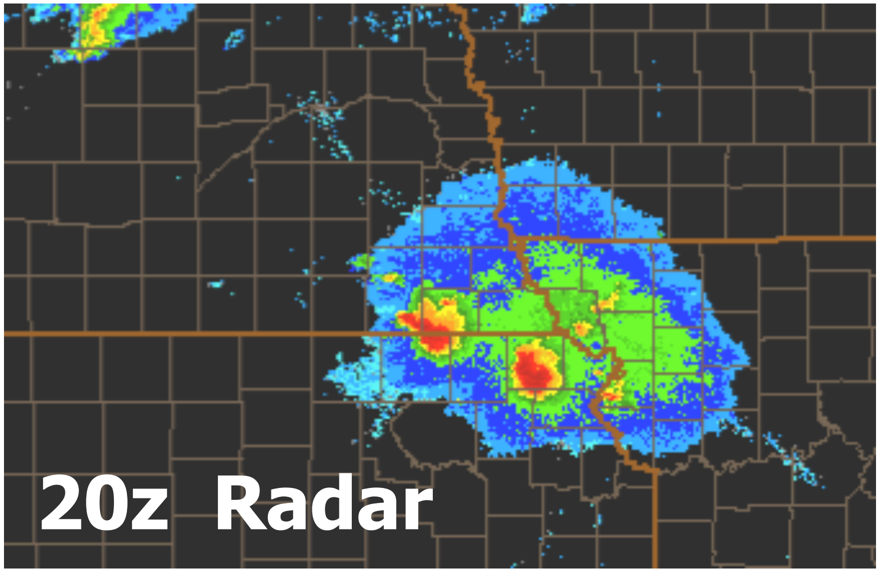
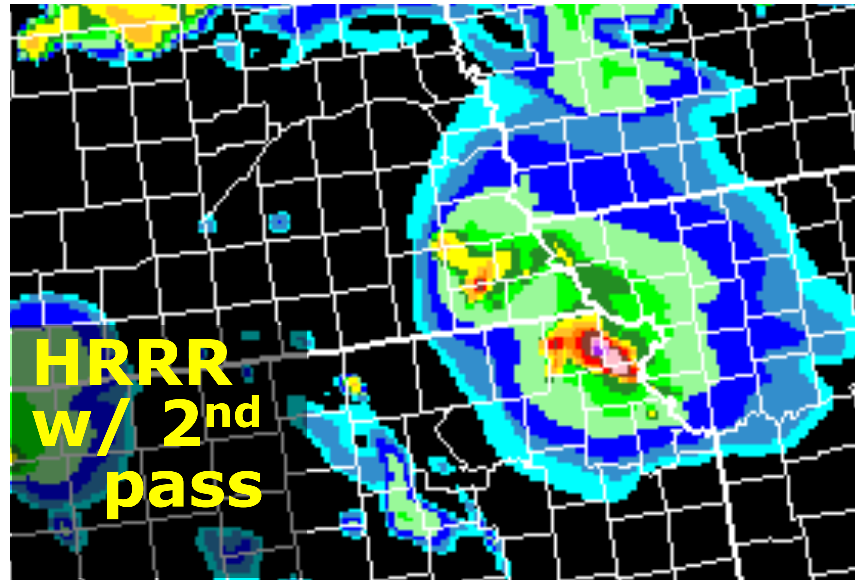
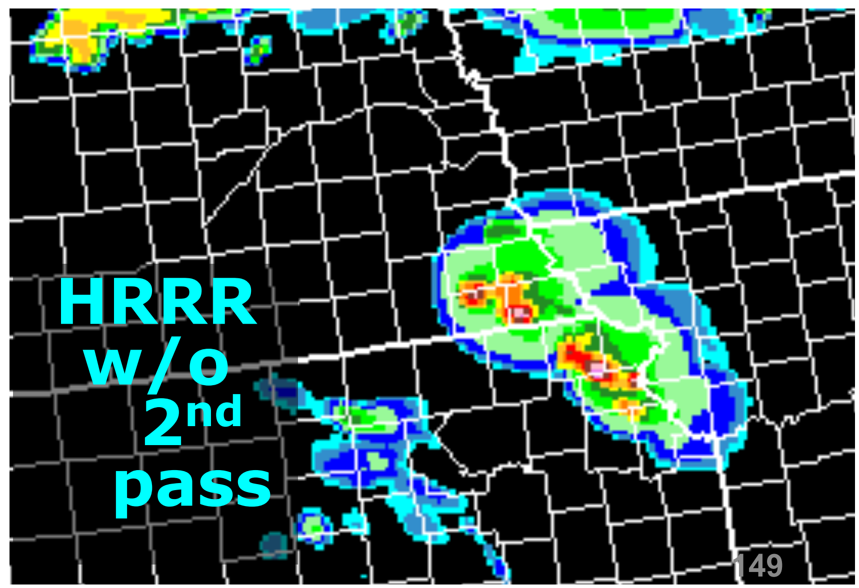
HRRR with 2nd pass radar DA on 3-km domain





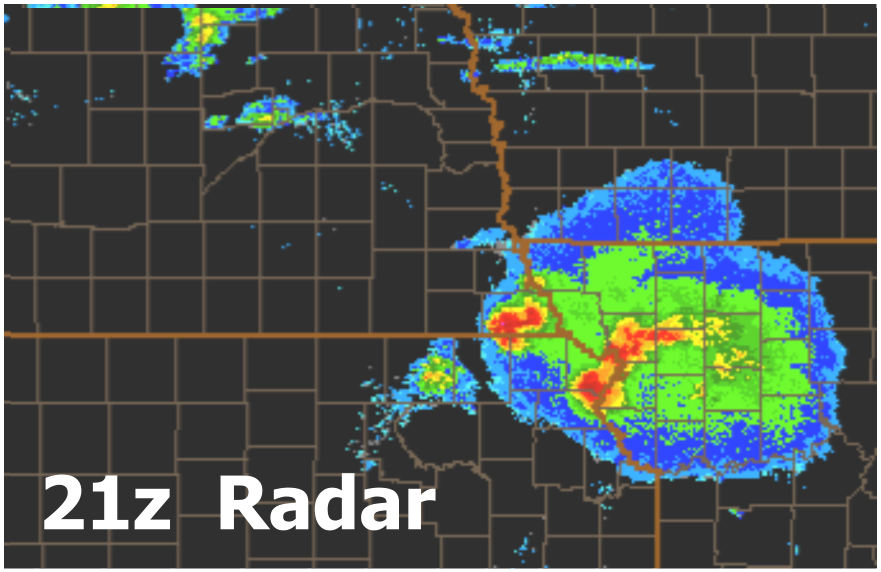
27 June 2009

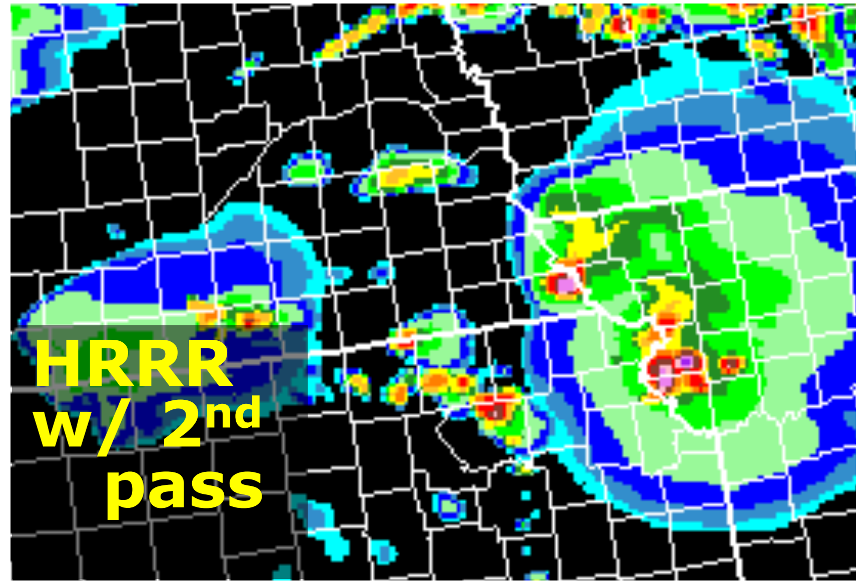
+ 2h
fcsts



- Both forecasts have RUC 13-km DFI reflectivity assim.
- 2nd pass (3-km DFI radar DA) greatly reduces initial spin-up

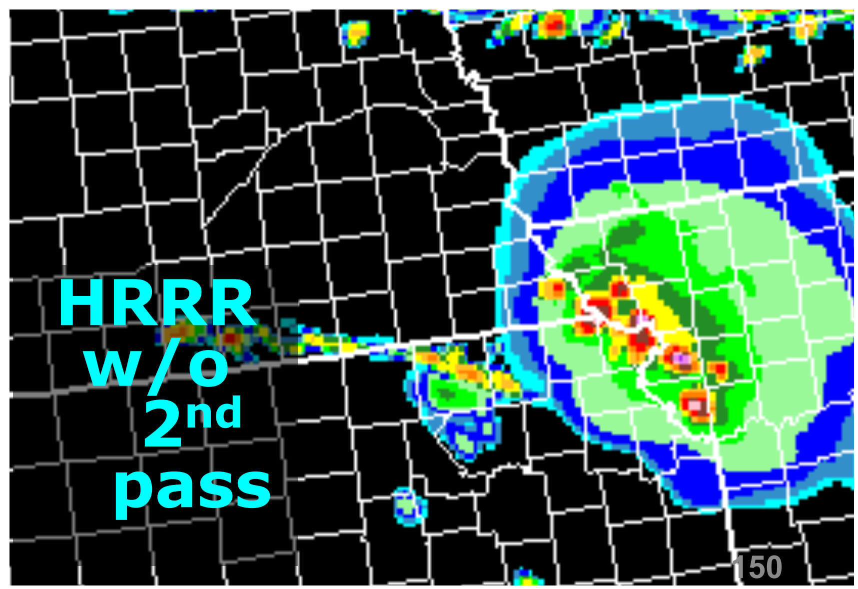
HRRR with 2nd pass radar DA on 3-km domain





27 June 2009

+ 3h
fcsts



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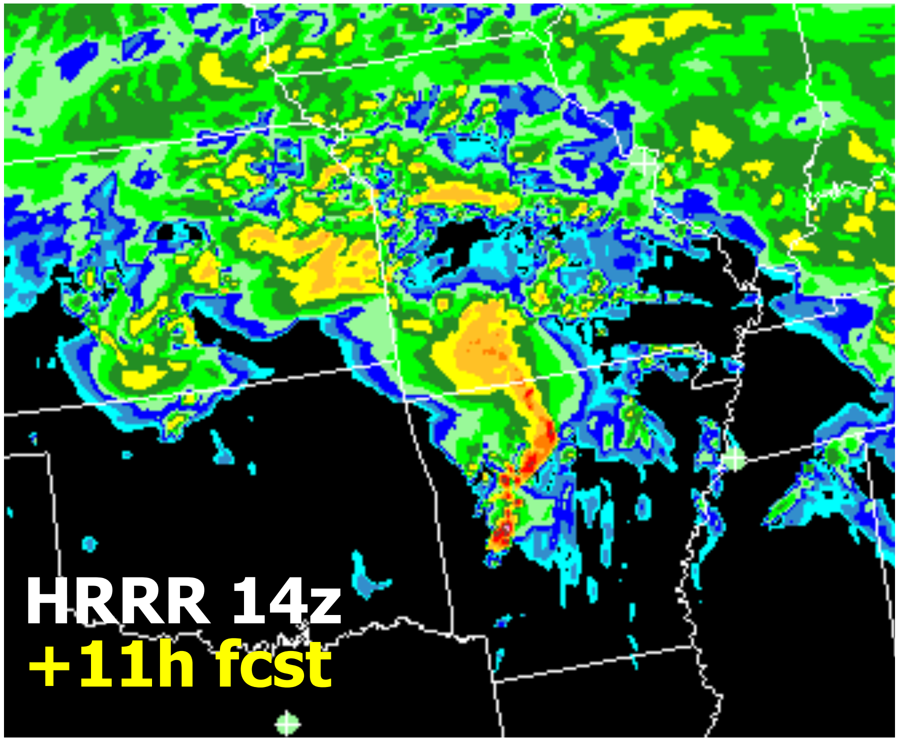
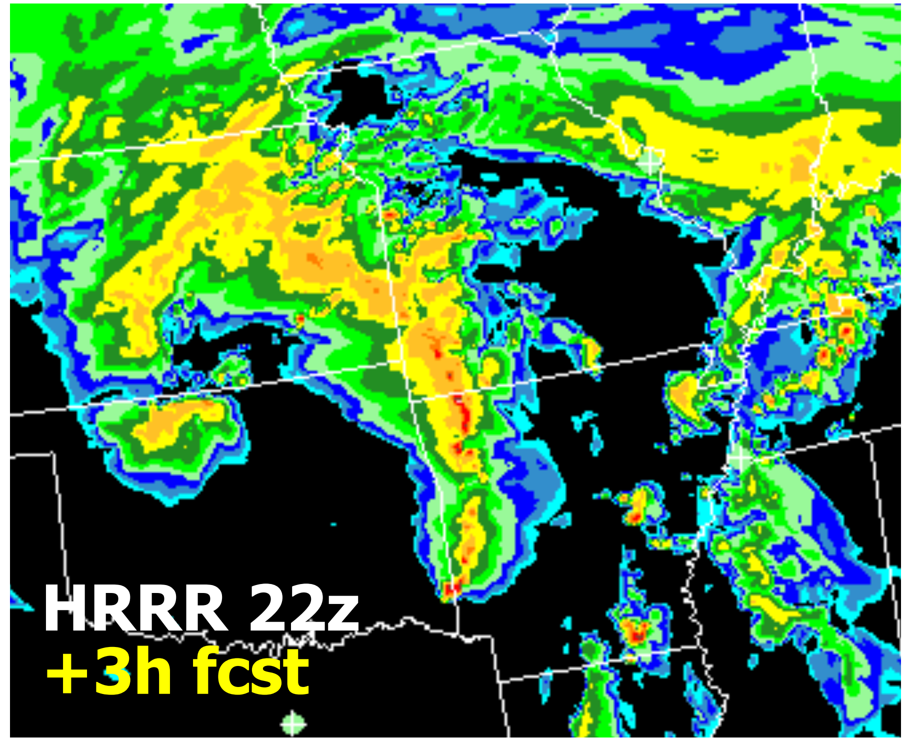
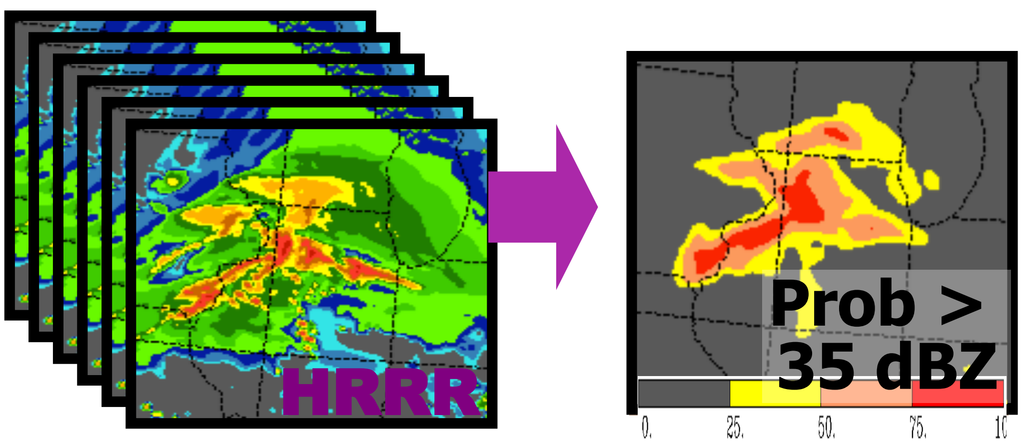
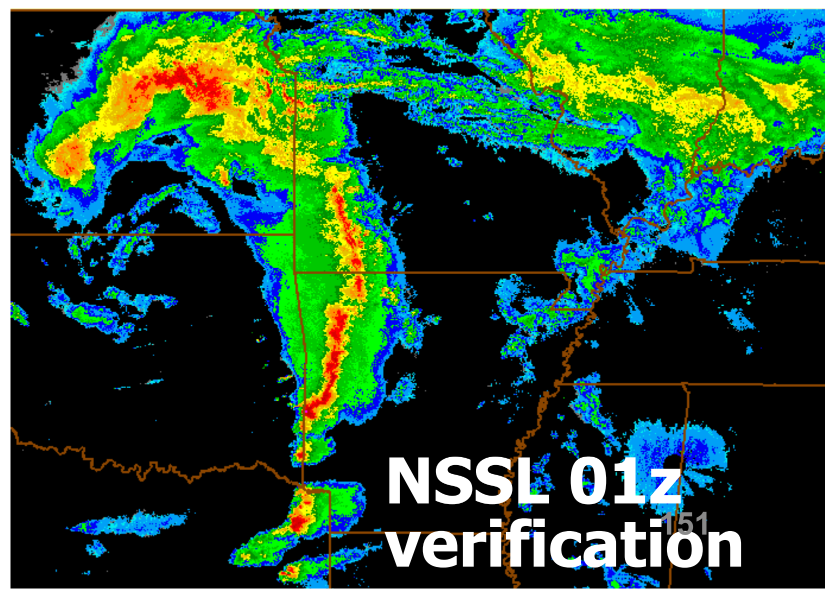




Valid 01z 10 Apr

Probabilistic guidance from HRRR time-lagged ensembles





The HCPF

HRRR Convective Probabilistic Forecast (HCPF)

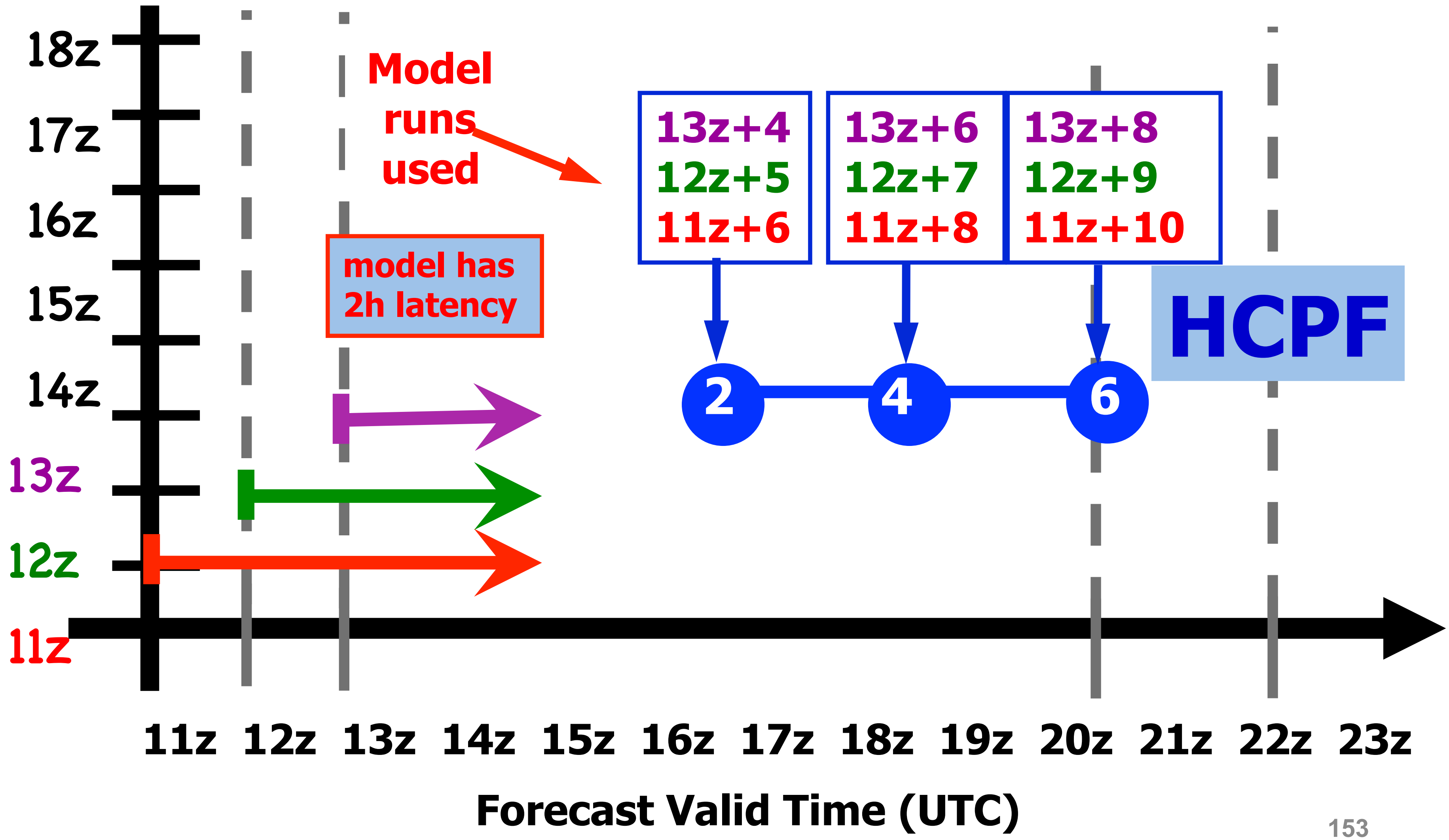
Identification of moist convection using model forecast fields:

- Stability – Surface lifted index < +2°C (neutral to unstable)
- Intensity – Model reflectivity > 30 dBZ or updraft > 1 m s^{-1}
- Time – 2 hr search window centered on valid times
- Location – Stability and intensity criteria searched within 25 points (radius of ~78 km) of each point for each member

$$\text{HCPF} = \frac{\text{\# grid points matching criteria over all members}}{\text{total \# grid points searched over all members}}$$

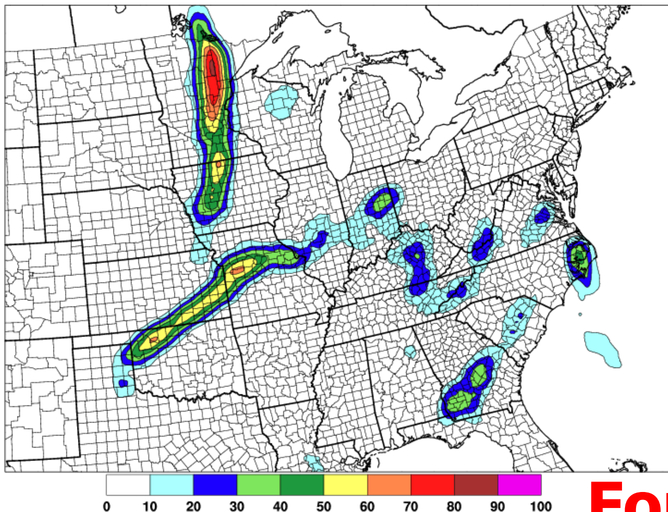
Time-lagged ensemble

Example: 15z + 2, 4, 6 hour HCPF

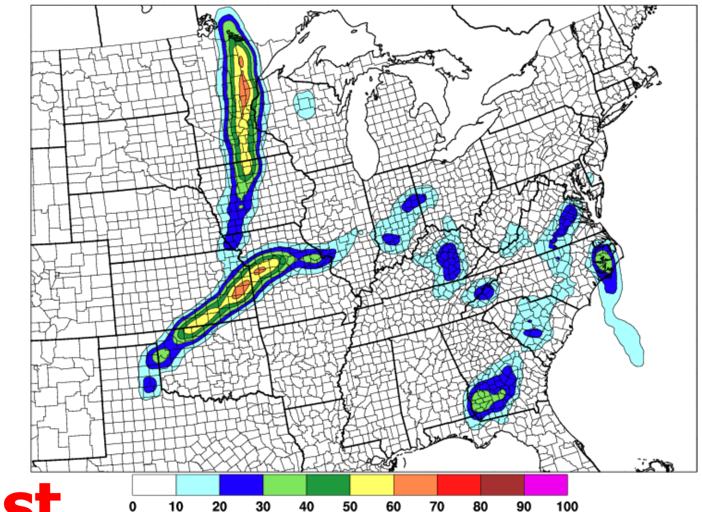


HCPF Example: 23 UTC 15 May 2009

10 hr forecast

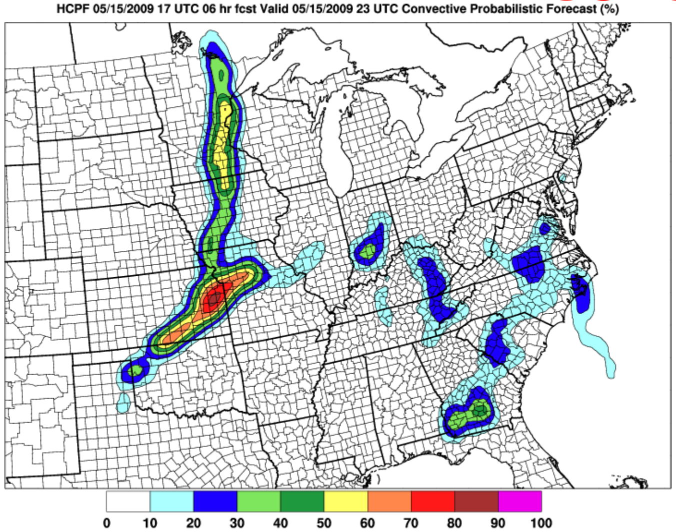


08 hr forecast

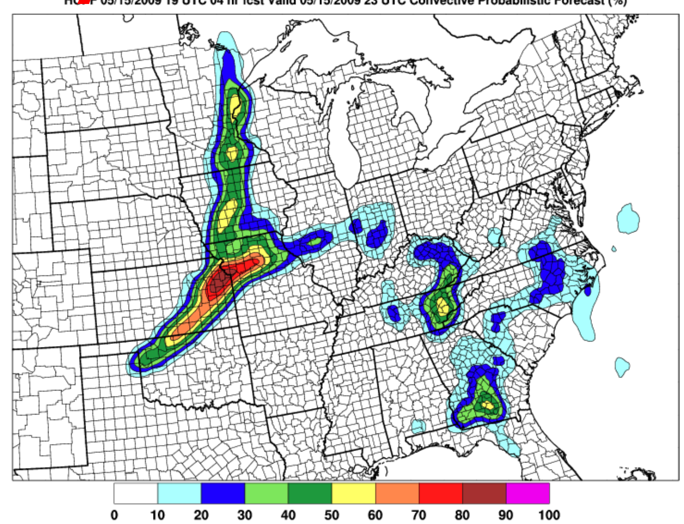


Forecast Consistency

06 hr forecast

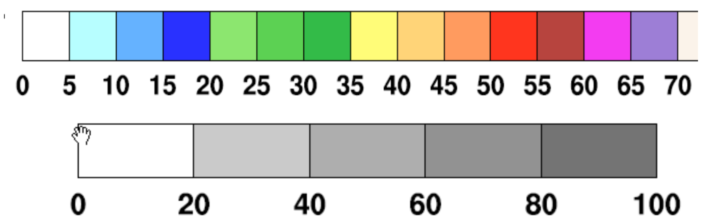


04 hr forecast



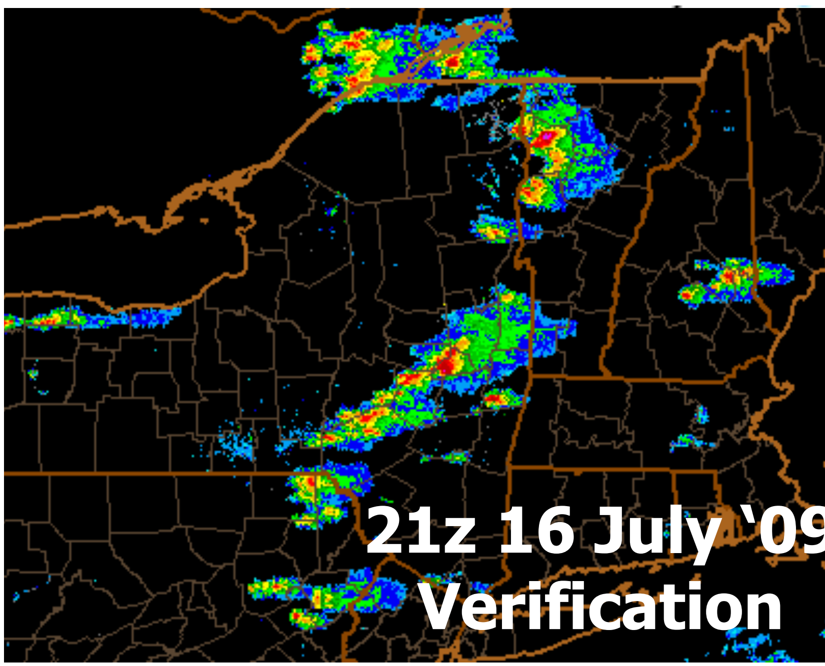
Convective probability forecasts from HRRR time-lagged ensemble

(shown with deterministic fcst)

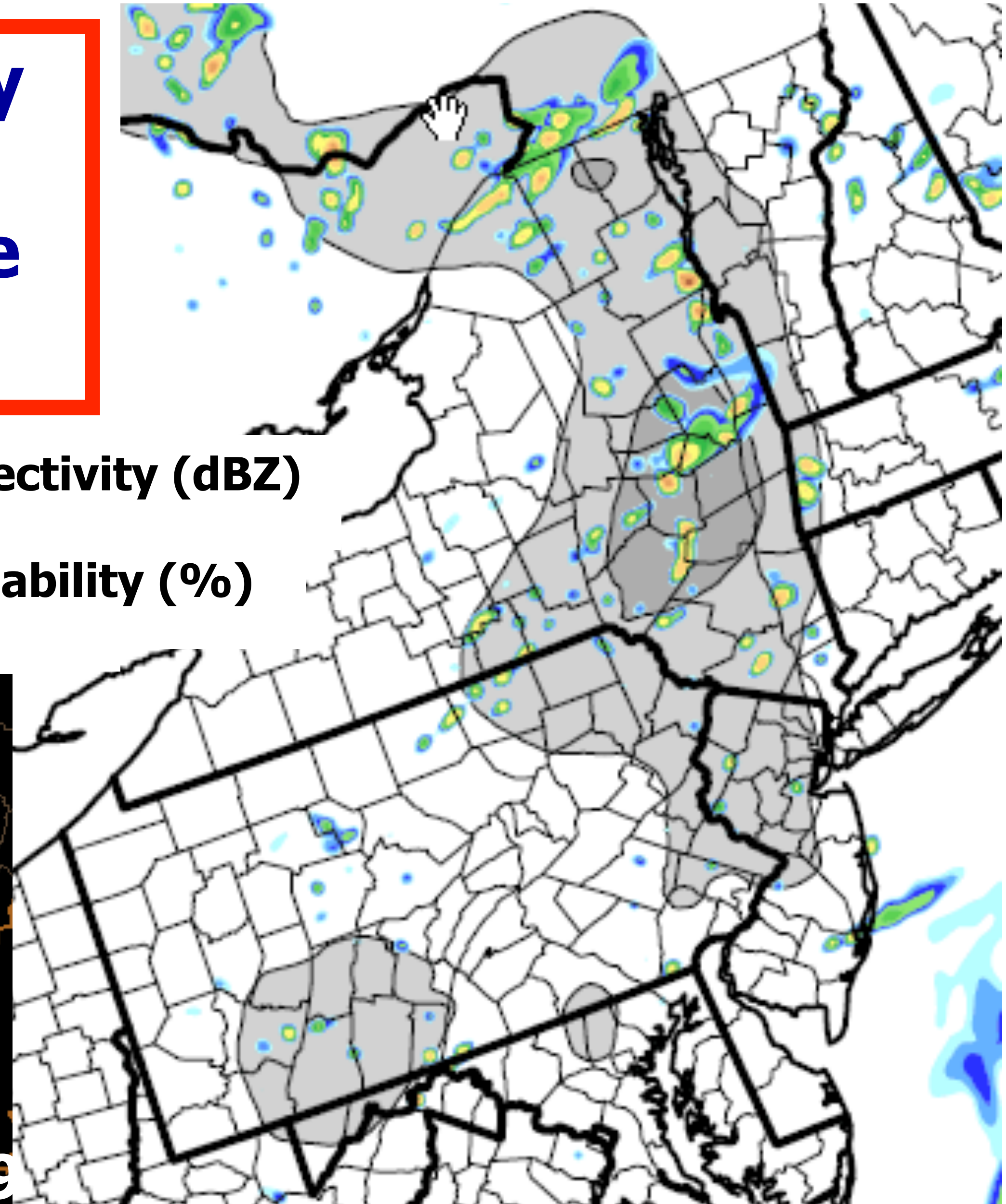


Reflectivity (dBZ)

Probability (%)



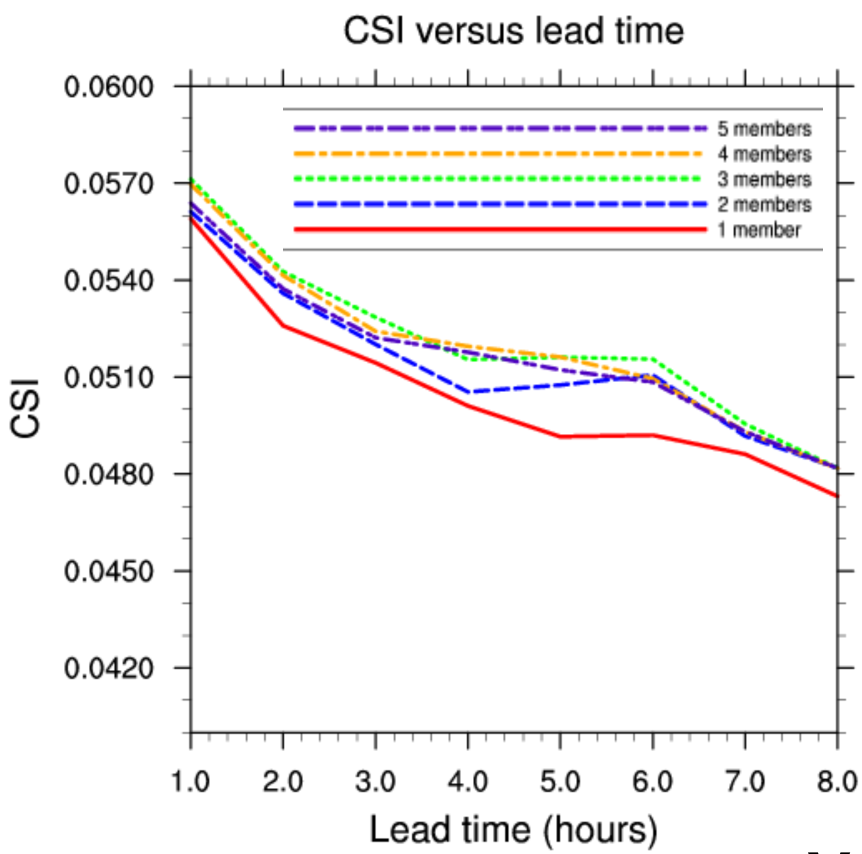
21z 16 July '09 Verification

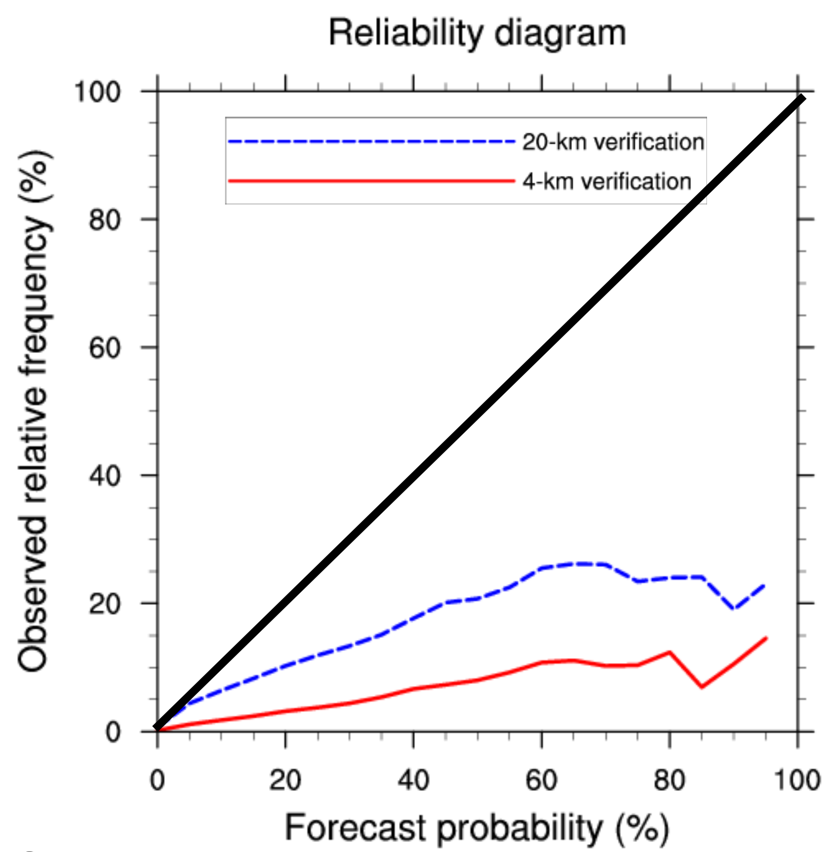


15z + 6h HRRR and HCPF

HCPF probability verification

40% probability verified on a 4-km grid

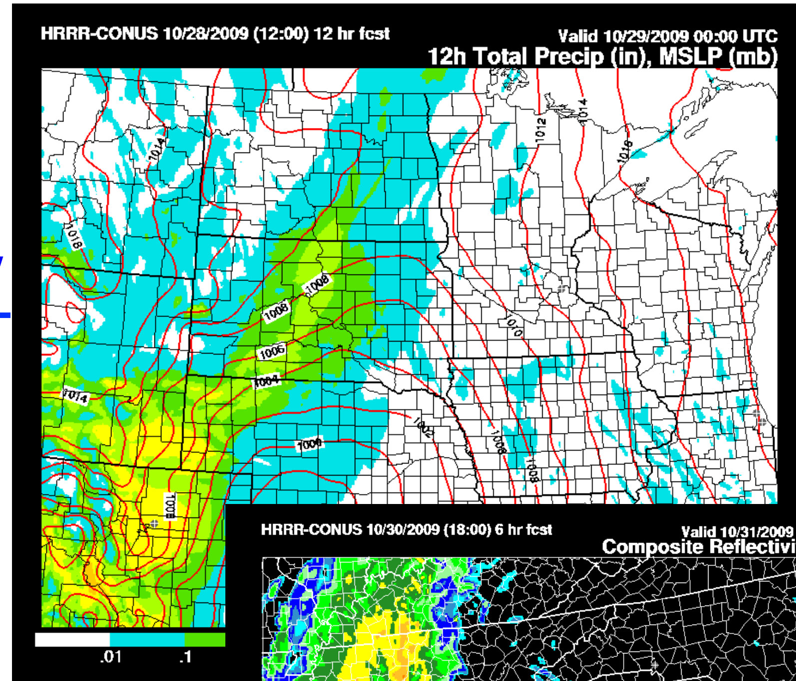




Verification period
August 2009 - 540 forecasts

Real-Time HRRR

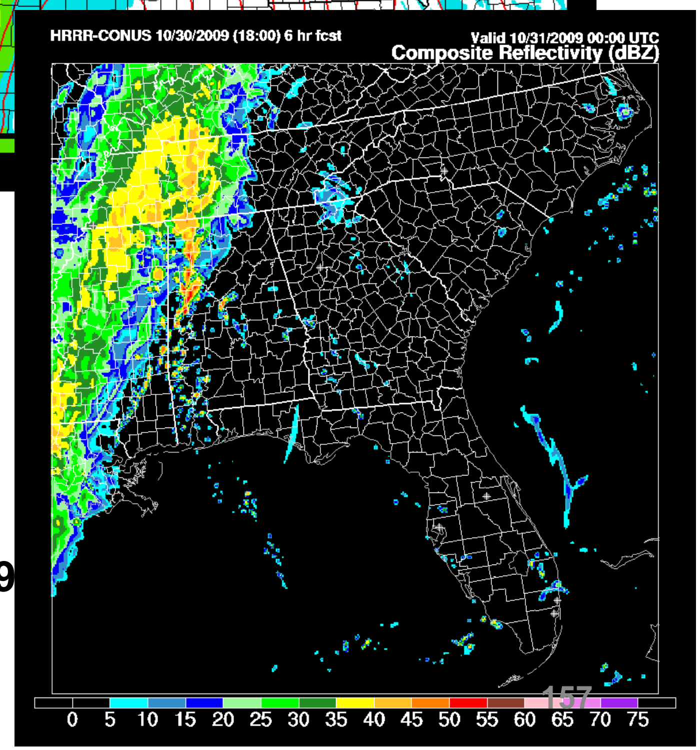
Front Range Winter Storm
12 hr fcst valid 00z 29 Oct 2009



http://rapidrefresh.noaa.gov/hrrrconus/

	All times	Loop	Valid Time													
			Fri 18	Fri 19	Fri 20	Fri 21	Fri 22	Fri 23	Sat 00	Sat 01	Sat 02	Sat 03	Sat 04	Sat 05	Sat 06	
			Forecast Duration													
			00	01	02	03	04	05	06	07	08	09	10	11	12	
all fields			18	19	20	21	22	23	00	01	02	03	04	05	06	all fields
1 km agl reflectivity	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	1 km agl reflectivity
reflectivity	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	reflectivity
max reflectivity	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max reflectivity
surface CAPE	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	surface CAPE
surface CIN	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	surface CIN
mixed CAPE	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	mixed CAPE
most unstable CAPE	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	most unstable CAPE
best LI	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	best LI
LCL	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	LCL
0-1 km shear	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-1 km shear
0-6 km shear	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-6 km shear
0-1 km helicity, storm motion	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-1 km helicity, storm motion
0-3 km helicity, storm motion	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	0-3 km helicity, storm motion
max updraft helicity	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max updraft helicity
max vert int graupel	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max vert int graupel
max 10m wind	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	max 10m wind
10m wind	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	10m wind
skin temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	skin temp
2m temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	2m temp
2m temp - skin temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	2m temp - skin temp
2m dew point	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	2m dew point
precipitable water	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	precipitable water
1h acc precip	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	1h acc precip
total acc precip	✔	✔		19	20	21	22	23	00	01	02	03	04	05	06	total acc precip
snow water equiv	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	snow water equiv
precip type	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	precip type
850mb temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850mb temp
850mb wind	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850mb wind
850mb rh	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850mb rh
850-500mb mean rh	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	850-500mb mean rh
700mb temp	✔	✔	18	19	20	21	22	23	00	01	02	03	04	05	06	700mb temp

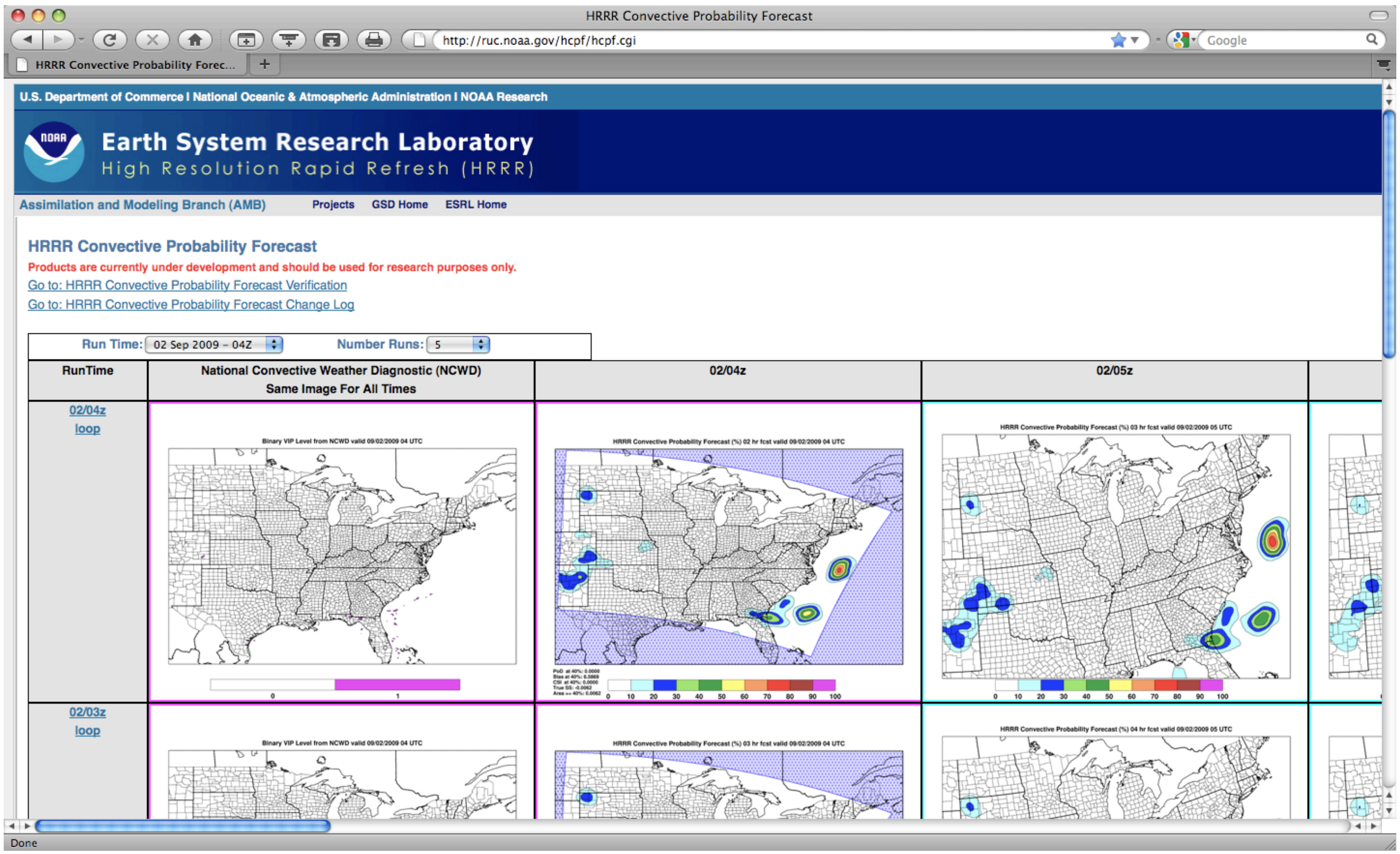
Squall-line with leading supercells
6 hr fcst valid 00z 31 Oct 2009



Diversity of convective-scale forecast fields

Real-Time HCPF

http://ruc.noaa.gov/hcpf/hcpf.cgi



HCPF generation time

Current verification - HCPF lead times

Summary on HRRR

- Now CONUS-wide forecasts at 3 km scale

- Captures information of convective-scale structure and evolution not represented by lower-resolution models using parameterization

- Radar assimilation essential for accurate storm-scale prediction

- HRRR Convective Probabilistic Forecast (HCPF) via time-lagged ensemble shown to have comparable skill to other convective forecasts including the RUC convective probabilistic forecast (RCPF)

Rapid Refresh / RUC Technical Review - OUTLINE

1:30 – 1:45 RUC➔RR transition overview,
NCEP RUC changes – 2008-09- Stan Benjamin

1:45 – 2:00 Observation impact experiments
- TAMDAR aircraft obs w/ moisture, larger OSE
Bill Moninger

2:00 – 2:20 Rapid Refresh overview, assimilation –
Steve Weygandt, Ming Hu

2:20 – 2:30 -- Break --

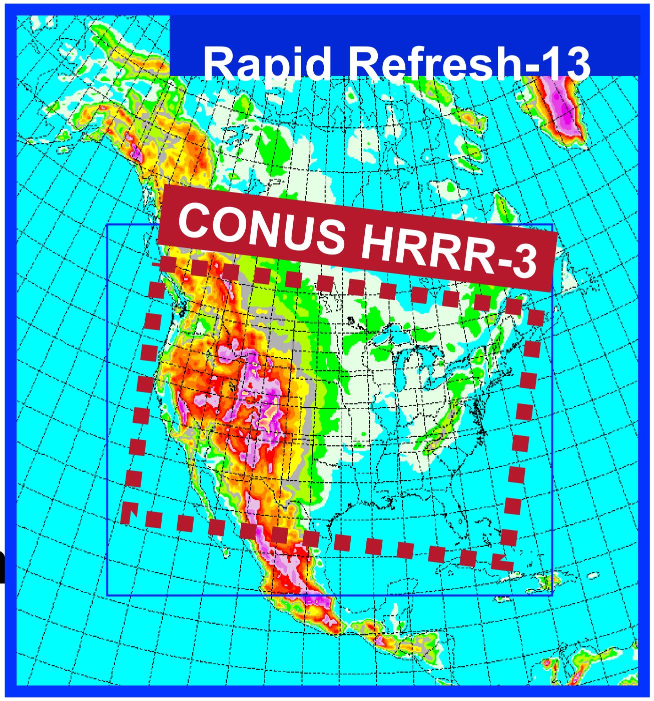
2:30 – 3:05 RR-WRF model development / testing
– physics, cloud, chemistry, PBL
John Brown, Tanya Smirnova, Joe Olson

3:05 – 3:20 The HRRR and HCPF (HRRR prob forecast)
Curtis Alexander

3:20 – 3:30 Future of RR/HRRR/ens Stan Benjamin

Relationship of HRRR to RR

- HRRR runs as a *nest* within RUC, will be transitioned to a nest within Rapid Refresh
- Data assimilation for HRRR is within RUC, will be within the RR
  - RR has same radar assimilation capability as RUC, improved assimilation for satellite data
  - Supplemental radar assimilation planned for HRRR 3-km grid
  - Assimilation of conventional observations and satellite data will likely remain on 13-km grid (computer cost, effectiveness)
  - HRRR with radar assimilation essential for convection, evaluation needed for other aviation hazards

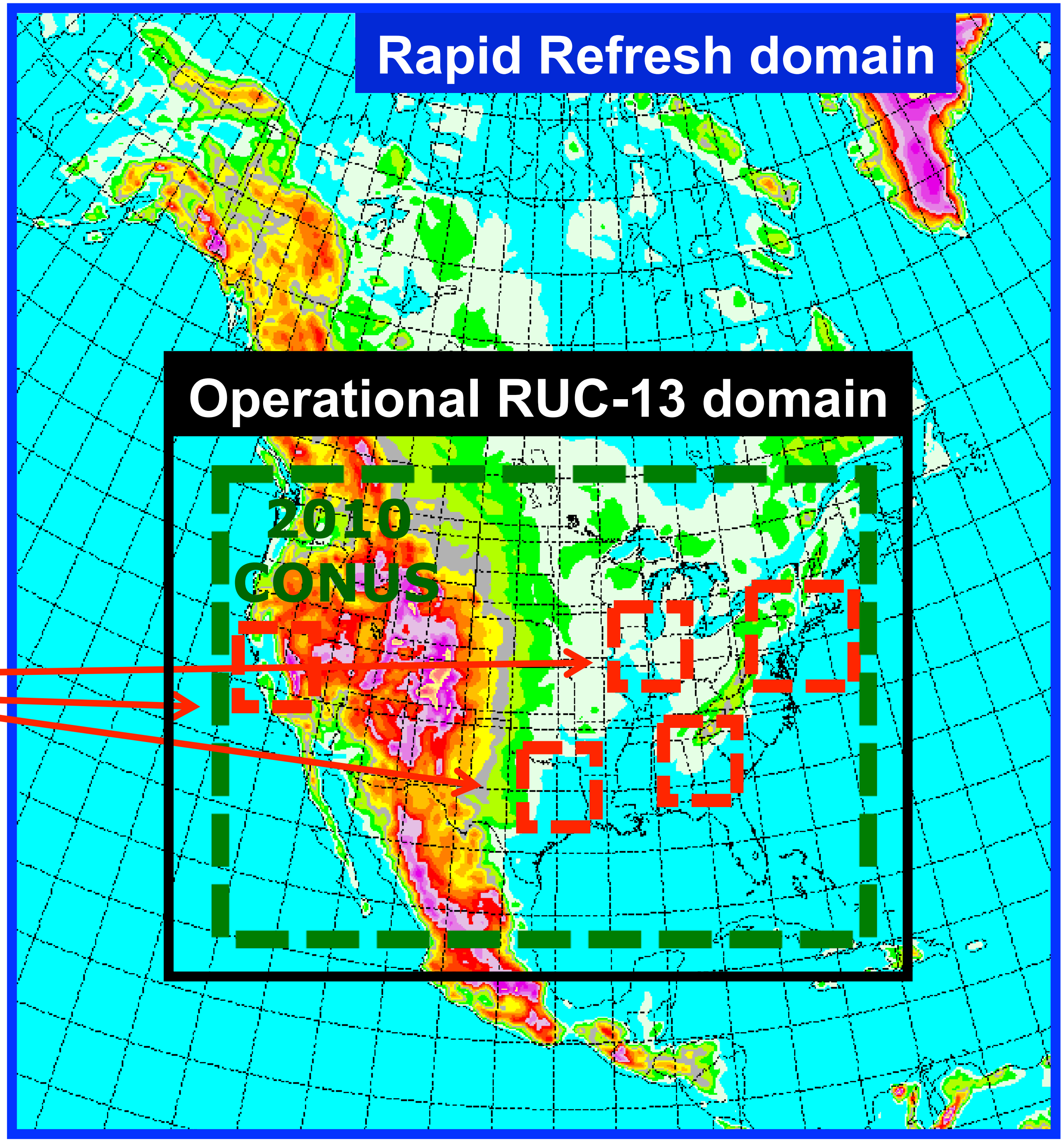


Rapid Refresh, HRRR, +0.5-1.0km HRRR subnests

HRRR – CONUS

Planned HRRR 1-km subnests (2-way boundary!) – testing

RR/HRRR Applications – aviation, severe wx, renewable energy, AQ, fire, hydro



Coordinated Meso- and Storm-scale ensembles
The NARRE and the HRRRE

2012-2013

NAM/Rapid Refresh ENSEMBLE (NARRE)

- **NEMS-based NMMB and ARW cores & GSI analysis**
- **Common NAM parent domain at 10-12 km (even larger than initial Rapid Refresh domain)**
- **Initially ~6 member ensemble made up of equal numbers of NMMB- & ARW-based configurations**
- **Hourly updated with forecasts to 24 hours**
- **NMMB & ARW control assimilation cycles with 3 hour pre-forecast period (catch-up) with hourly updating**
- **NAM 84 hr forecasts are extensions of the 00z, 06z, 12z, & 18z runs.**

Coordinated Meso- and Storm-scale ensembles
The NARRE and the HRRRE

2012-2013

High-Resolution Rapid Refresh Ensemble (HRRRE)

- **Each member of NARRE contains**
  - 3 km CONUS and Alaskan nests
  - Control runs initialized with radar data
- **Positions NWS/NCEP/ESRL to**
  - Provide NextGen enroute and terminal guidance
  - Provide probability guidance
  - Improve assimilation capabilities with radar and satellite
  - Tackle Warn-on-Forecast as resolutions evolve towards ~1 km

Very **Short-Range Ensemble Forecasts - VSREF**

- Updated hourly w/ available members valid at same time

VSREF members

RR – hourly
time-lagged (TL) ensemble members
- 2012 - ensemble RR

ESRL 3km HRRR (incl. TL ensemble)
- 2012 - proposed HRRR at NCEP
- future HRRRE from NARRE

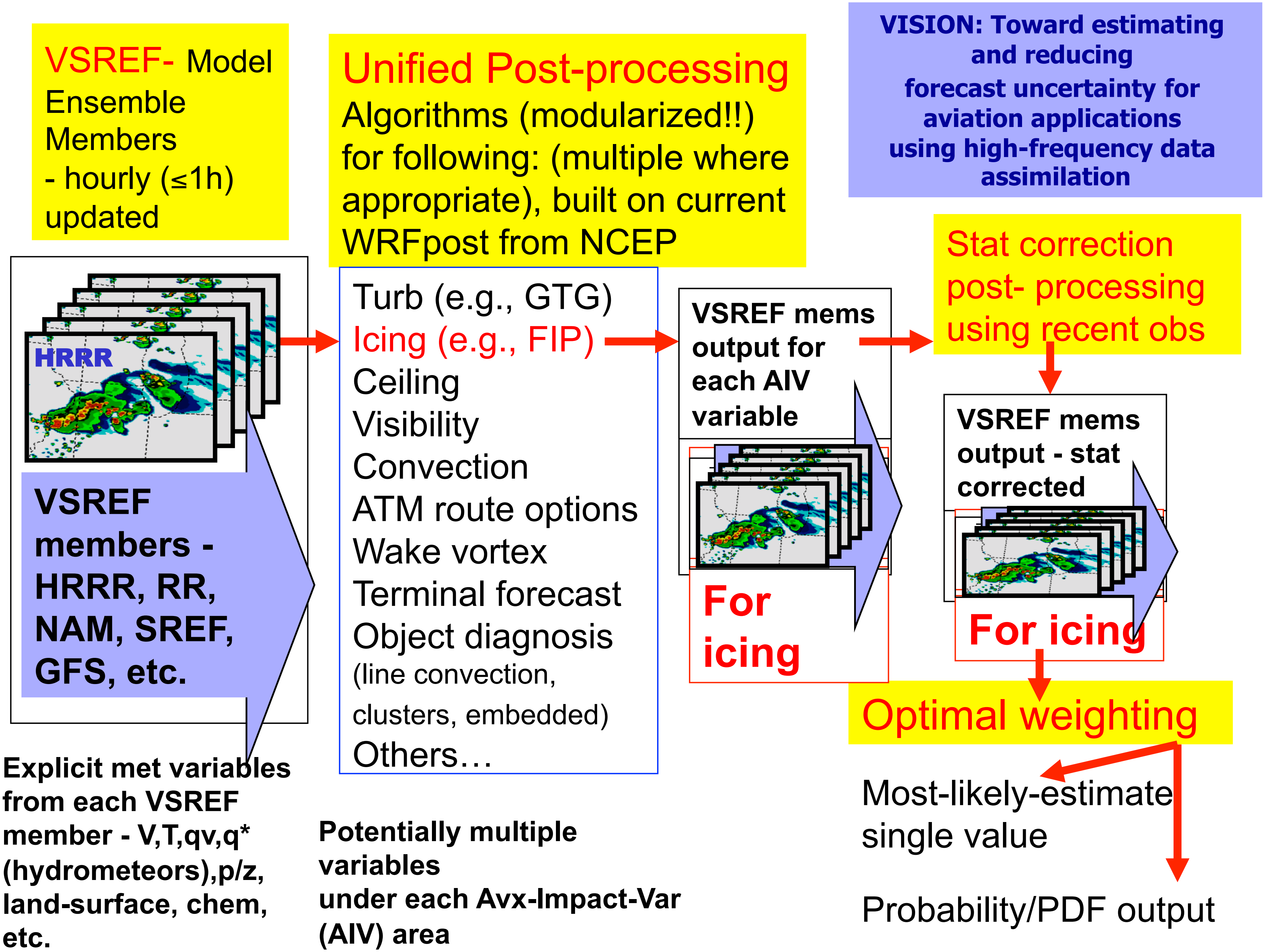
NAM / NAM ensemble

GFS / GFS ensemble

SREF (updated every 6h)

VSREF –
Hourly
Updated
Probabilistic
Forecasts
= TL+
ensemble

Time-lagged ensemble provides skill baseline for evaluating HRRRE and NARRE development

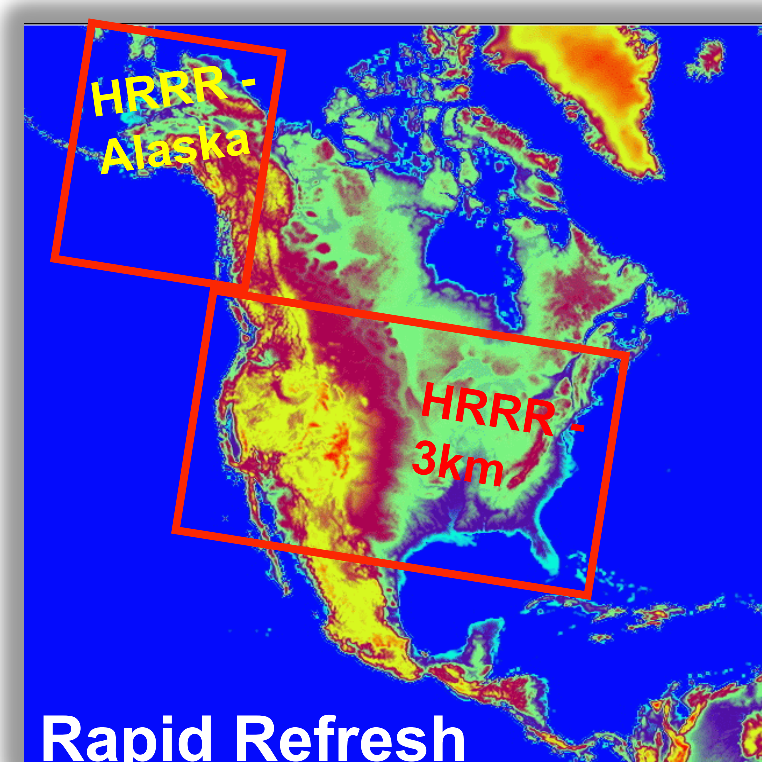

VSREF- Model Ensemble Members
- hourly (≤1h) updated
Unified Post-processing Algorithms (modularized!!) for following: (multiple where appropriate), built on current WRFpost from NCEP
VISION: Toward estimating and reducing forecast uncertainty for aviation applications using high-frequency data assimilation
HRRR
VSREF members - HRRR, RR, NAM, SREF, GFS, etc.
Turb (e.g., GTG)
Icing (e.g., FIP)
Ceiling
Visibility
Convection
ATM route options
Wake vortex
Terminal forecast
Object diagnosis
(line convection, clusters, embedded)
Others…
VSREF mems output for each AIV variable
For icing
Stat correction post- processing using recent obs
VSREF mems output - stat corrected
For icing
Optimal weighting
Most-likely-estimate single value
Probability/PDF output
Explicit met variables from each VSREF member - V,T,qv,q* (hydrometeors),p/z, land-surface, chem, etc.
Potentially multiple variables under each Avx-Impact-Var (AIV) area

Trends from our perspective - 2007

- Use of high-frequency NWP data continues to grow with increasing automation of decision-making, access to gridded data
- More interaction with intermediary developers of post-processing products, esp. probabilistic products
- Common development/implementation with NOAA – ESMF beyond WRF
- Ensemble Rapid Refresh
- Common computing system in NOAA
- Increasingly coupled environmental systems

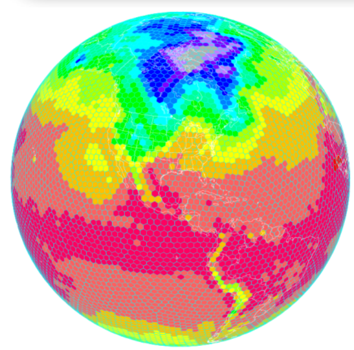
Future plans (in collaboration with NCEP)

2010 – Rapid Refresh operational at NCEP
2012 – Operational (NCEP) CONUS-wide High Resolution Rapid Refresh nested inside RR
2013 – Ensemble RR (~6 members, ARW, NMM cores)
2014 – Add operational Alaska HRRR
2015 – Ensemble CONUS HRRR (6 members)
2017 – Global Rapid Refresh (GRR)



Incorporation of inline chemistry – 2012-15

- Assimilation of radial wind, new satellite, phased-array radar, CASA, new regional aircraft, chemistry obs…
- Frequency from 60min→30→15min
- 1h EnKF
- Improved nowcast/blend/NWP
- Ensemble-based post-processing



Applications:
Aviation, severe wx, Hydrology, energy, air quality, fire weather, volcanoes/hazards, etc.